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Cover: *Farmers evaluating soybean varieties in Murambi, Umutara, Rwanda.* Photo by IITA.

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EDITOR'S NOTE

Back to stay

IITA was the first major African link in the integrated network of international agricultural research centers. It was also one of the first centers that engaged in farming systems research. In the 1980s and 1990s, the Institute had a very strong program on natural resource management (NRM), covering aspects of soil fertility management, cropping system diversification, and improved agronomy. This, along with the emphasis on the genetic improvement of the major food crops in the humid tropics, provided an integrated program of research on sustainable agricultural development.

Over the past fifteen years, the focus of research-for-development activities at IITA shifted away from NRM, party driven by changes in the investment portfolios of important donors. With the area of soils and natural resources back on top of the development agenda and recognizing that the potential of improved germplasm can only be realized in the presence of appropriate crop and nutrient management practices, IITA has recently decided to increase its investments in NRM research for development with a particular focus on soils.

The March 2012 issue of R4D Review commemorated IITA’s 45 years. It focused on the successes, challenges, and prospects of the genetic improvement programs; these are key to the Institute’s success in improving food crop production in sub-Saharan Africa. Innovations in genetic improvement have shown how enhanced crop productivity, along with other ingredients, such as capacity building and policies, has helped to lift millions out of poverty.

This second issue for the year highlights our important work that is being undertaken in partnership with national and international institutions in the area of sustainable NRM in sub-Saharan Africa. It also signals IITA's renewed focus on this area of research. The articles cover the three main pillars of the NRM research-for-development agenda: (1) Integrated Soil Fertility Management, aiming at enhancing crop productivity following agroecological principles, with a livelihood focus, (2) Sustainable Land Management, aiming at rehabilitating soils for the provision of other essential ecosystem services, with a landscape focus, and (3) Climate Change, aiming at enhancing the resilience of farming systems to climate variability.

The CGIAR Research Programs or CRPs are the result of the restructuring of the CGIAR’s research agenda. The last article explains the components of this new framework that involve NRM-related activities at IITA and shows how these contribute to the success of these CRPs.

In this issue also readers will get to "meet" the team in IITA who are conducting NRM research, and read about the perspectives of the Chair of the CGIAR Consortium Board, Carlos Pérez del Castillo, on the reforms as they affect IITA.

“The soil nutrient losses in sub-Saharan Africa are an environmental, social, and political time bomb. Unless we wake up soon and reverse these disastrous trends, the future viability of African food systems will indeed be imperiled.”

- Dr Norman Borlaug, 14 March 2003, Muscle Shoals, Alabama, USA

NEWS

Ensuring good quality commercial products

The 'Institutionalization of quality assurance mechanism and dissemination of top quality commercial products to increase crop yields and improve food security of smallholder farmers in sub-Saharan Africa,' or Commercial Products (COMPRO-II) project, was launched this year in Dar es Salaam, Tanzania.

Supported by the Bill & Melinda Gates Foundation, this project aims to institutionalize quality assurance mechanisms and facilitate the rapid dissemination of top quality commercial products to increase yields and improve the food security of smallholder farmers in the region.

This will be done by raising awareness among over two million smallholder farmers on effective and profitable commercial products by 2016 through public-private partnership.

COMPRO II will:

1. transit technologies (e.g., Rhizobium inoculants for legumes, mycorrhizal inoculants for banana, and seed coating for maize) that enhance yields by 15–30% identified in COMPRO I into Ghana, Tanzania, and Uganda,
2. institutionalize regulatory and quality control processes,
3. disseminate effective products through public-private partnerships,
4. develop communication tools, and
5. strengthen human capacity.

Partners include the African Agricultural Technology Foundation (AATF), Alliance for a Green Revolution in Africa – Soil Health Program (AGRA), Farm Input Promotions (FIPS), the Tropical Soil Biology and Fertility Research Area of the International Centre for Tropical Agriculture (TSBF-CIAT), the Centre for Agricultural Bioscience International (CABI), and universities, national research organizations, extension organizations, and quality control entities in the different target countries.

Nigeria releases Vitamin A maize

The Nigerian Government has released two new maize hybrids that can provide more vitamin A in the diets of millions in the country.

Vitamin A deficiency is prevalent in Nigeria, especially among children, pregnant women, and mothers. It lowers immunity and impairs vision, which can lead to blindness and even death.

The hybrids, which are the first generation vitamin A-rich maize, were released by the National Variety Release Committee of Nigeria as Ife maizehyb 3 and Ife maizehyb 4. They are recognized as IITA hybrids A0905-28 and A0905-32, respectively. The hybrids are a product of nearly a decade of breeding for enhanced

Vitamin A-rich maize developed by IITA with the Institute of Agricultural Research & Training, Nigeria. Photo by IITA.

levels of pro-vitamin A. Provitamin A is converted by the body into vitamin A when the maize is eaten.

The hybrids were developed by IITA with the Institute of Agricultural Research & Training (IAR&T) using conventional breeding in a project funded by HarvestPlus—a Challenge Program of the CGIAR as part of strategies to address the prevalence of vitamin A deficiency.

Other collaborating partners include the Institute for Agricultural Research (IAR), Zaria; University of Maiduguri; International Maize and Wheat Center (CIMMYT), University of Illinois, and University of Wisconsin.

Tanzania and partners launch initiatives to tackle cassava disease

Tanzania's Ministry of Agriculture, Food Security and Cooperatives (MAFC) and the Bill & Melinda Gates Foundation have launched three new projects to support efforts to develop cassava varieties with resistance to Cassava Mosaic Disease (CMD) and Cassava Brown Streak Disease (CBSD) and to establish more sustainable seed systems to provide smallholder farmers better access to such varieties.

The projects were launched during a cassava value

Root with cassava brown streak disease. Photo by IITA.

chain event in Dar es Salaam that brought together representatives from the government, donor community, private sector and development partners.

Farmers in Tanzania and the region need access to planting materials of new improved varieties released in the country. Cassava is a very important crop not only for food security but it also has great potential as a cash crop through processing. The two diseases, especially CBSD, are a major problem and need to be urgently addressed.

The Cassava Varieties and Clean Seed to Combat CBSD and CMD (5CP) project will facilitate sharing of five of the best varieties from Tanzania, Kenya, Malawi, Mozambique, and Uganda for regional testing across the countries to speed up the development of varieties with dual resistance to the two diseases.

Building African breeders' capacities

IITA and the West Africa Center for Crop Improvement (WACCI) have signed a memorandum of understanding aimed at increasing the number of plant breeders in Africa.

IITA researcher training farmers and partners from national agricultural research systems. Photo by IITA.

Under the agreement, WACCI, a center at the University of Ghana, will send postgraduate students to IITA for three years to carry out research in plant breeding. Students will have access to IITA facilities and will be supervised by senior IITA scientists.

The alliance with WACCI is expected to halt the dwindling number of plant breeders in Africa and boost IITA's role in building capacity in the continent. Building capacities of breeders is one way of helping ensure food security in Africa.

In its 45 years of existence as Africa's leading research partner, IITA has trained more than 74,000 people in Africa and elsewhere. Some of these beneficiaries today occupy strategic positions in Africa.

Former President Olasegun Obasanjo, IITA Goodwill Ambassador, with IITA Scientist Ranajit Bandyopadhyay, looks at exhibits during his recent visit to IITA. Photo by IITA.

Visitors

Former Nigerian President Olusegun Obasanjo, IITA Goodwill Ambassador, visited the Institute recently, calling for investments to rejuvenate research institutions such as IITA.

IFAD president Kanayo Nwanze talks about how committing more resources to research and development could help Africa achieve the much-awaited Green Revolution. Photo by IITA.

This call was echoed by **Dr Kanayo Nwanze**, President of the International Fund for Agricultural Development (IFAD), who also came to IITA to strengthen research and collaboration ties.

Increasing investments in agricultural research for development (R4D) is expected to bring the much-awaited agricultural transformation to Africa and help address the rising wave of youth unemployment and its attendant poverty, said Dr Nwanze.

According to him, investments in agricultural research and development will have a positive trickle down effect on the youths by way of generating improved technologies that could attract them to agriculture and also build their capacities in solving both present and future challenges to food security. Citing research studies, Dr Nwanze said that for every dollar invested in agricultural research, returns on investments were about US$9 in sub-Saharan Africa.

Meanwhile, former Pres. Obasanjo emphasized that Africa needs to rethink its food import burden and consider 'local content' options, such as the inclusion of cassava flour in wheat to reduce the rising import bills. He views the 'local content' option as part of efforts to free up resources for infrastructural development and poverty alleviation in the continent.

Mr Carlos Pérez del Castillo, Chair of the Consortium Board of CGIAR; **Dr Frank Rijsberman**, Chief Executive Officer of the CGIAR Consortium; accompanied by **Dr Bruce Coulman**, IITA Board Chair; and Directors General **Dr Papa Seck** of AfricaRice, and **Dr Jimmy Smith** of the International Livestock Research Institute (ILRI) also visited IITA in July. The visit provided the top CGIAR management with the opportunity to talk to staff about the ongoing CGIAR reform and its implementation.

Mr Pérez del Castillo said that they very impressed with their interactions with IITA scientists and the high quality of science they are doing in various fields. He further said that "their degree of commitment and passion to IITA's mission of eradicating hunger and poverty through their science is nothing short of amazing."

The Chair of the Consortium Board, CGIAR during a tour of IITA. Photo by IITA.

Mr Carlos Pérez del Castillo, Chair of the Consortium Board, CGIAR. Photo by IITA.

He particularly cited IITA's "food production systems" approach to addressing agricultural constraints, stressing that such a strategy would greatly benefit farmers and help feed the world's growing population (see interview on pages 54-56 of this publication).

The CGIAR chief said that he sees IITA playing a vital role in leading holistic global research initiatives to find workable solutions to the challenges of agricultural underdevelopment, food insecurity, and natural resource degradation, given its impressive track record of research-based achievements in sub-Saharan Africa.

A CGIAR-commissioned study showed that IITA research is responsible for 70% of the CGIAR's impact in Africa.

Increasing productivity the ISFM way

Bernard Vanlauwe, b.vanlauwe@cgiar.org

The need to grow more food without depleting important natural resources makes the intensification of African agriculture essential. The Green Revolution in South Asia and Latin America raised crop productivity through the deployment of improved varieties, water, and fertilizer. However, efforts to achieve similar results in sub-Saharan Africa (SSA) have largely failed. The sustainable intensification of agriculture in SSA has gained support in recent years, especially in densely populated areas where natural fallows are no longer an option.

There is growing recognition that farm productivity is a major entry point to achieving success in overcoming rural poverty. A recent landmark event was the launching of the Alliance for a Green Revolution in Africa (AGRA). AGRA has adopted integrated soil fertility management (ISFM) as a framework for raising crop productivity through a reliance on soil fertility management technologies, with an emphasis on the increased availability and use of mineral fertilizer (www.agra-alliance.org). Within the refreshed IITA Strategy 2012–2020, ISFM is one of the main pillars of the natural resource management (NRM) research area.

Farm productivity has been cited as a major entry point to achieving success in overcoming rural poverty. Photo by IITA.

Whats is ISFM?

We defined ISFM as "A set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs, and improved germplasm combined with the knowledge on how to adapt these practices to local

Bernard Vanlauwe, R4D Director for the Central Africa Hub and the Natural Resource Management research area, IITA.

conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity. All inputs need to be managed following sound agronomic principles" (Vanlauwe et al. 2011a). The definition focuses on maximizing the efficiency with which fertilizer and organic inputs are used since these are both scarce resources in the areas where agricultural intensification is needed. Agronomic efficiency (AE) is defined as the extra crop yield obtained per unit of nutrient applied and is expressed in kg crop produced per kg nutrient input.

Fertilizer and improved germplasm

In terms of response to management, two general classes of soils are distinguished: responsive soils, i.e., soils that show acceptable responses to fertilizer (Path A, Fig. 1), and poor, less-responsive soils that show little or no response to fertilizer due to constraints apart from the nutrients contained in the fertilizer (Path B, Fig. 1). Sometimes, where land is newly cleared or where fields are close to homesteads and receive large amounts of organic inputs each year, a third class exists where crops show little response to fertilizer since the soils are fertile.

The ISFM definition proposes that the application of fertilizer to improved germplasm on responsive soils will raise crop yield and improve AE relative to the current farmers' practice. This is characterized by traditional varieties receiving poorly managed nutrient inputs and/or too little of them (Path A, Fig. 1). Major requirements for achieving production gains on responsive fields within Path A (Fig. 1) include the following: the use of disease-resistant and improved germplasm, crop and water management practices, and the application of the "4R" Nutrient Stewardship Framework—a science-based framework that focuses on applying the

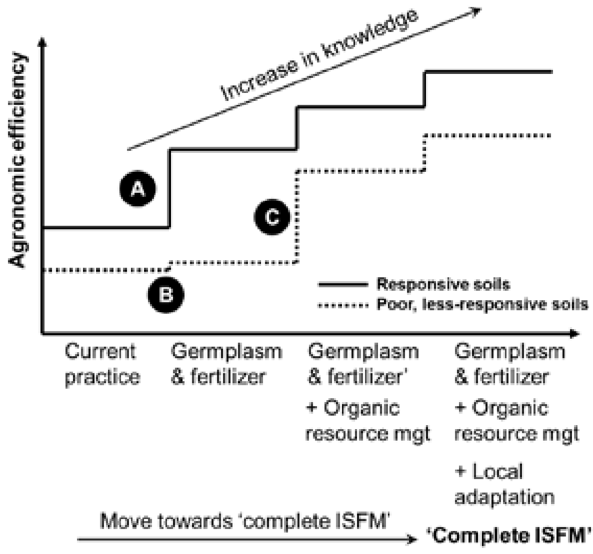

Figure 1. Conceptual relationship between the agronomic efficiency (AE) of fertilizers and organic resource and the implementation of various components of ISFM, culminating in complete ISFM towards the right side of the graph. Soils that are responsive to NPK-based fertilizer and those that are poor and less responsive are distinguished. The 'current practice' step assumes the use of the current average fertilizer application rate in SSA of 8 kg fertilizer nutrients/ha. Source: Vanlauwe et al. (2011a).

right fertilizer source at the right rate, at the right time during the growing season, and in the right place (Fig. 2). Poor, less-responsive soils should be avoided when deploying improved germplasm and fertilizer.

Combined application of fertilizer and organic inputs

Organic inputs contain nutrients that are released at a rate determined in part by their chemical characteristics or organic resource quality. However, organic inputs applied at realistic rates seldom release sufficient nutrients for optimum crop yield. Combining organic and mineral inputs has been advocated for smallholder farming in the tropics because neither input is usually available in sufficient quantities to maximize yields and because both are needed in the long term to sustain soil fertility and crop production. Substantial enhancements in fertilizer AE have been observed in an analysis related to N fertilizer applied to maize in Africa, but these were strongly influenced by the quality and application rate of the organic resources (Fig. 3).

An important question arises within the context of ISFM: Can organic resources be used to rehabilitate less-responsive soils and make these responsive to fertilizer (Path C in Fig. 1)? In southwestern Nigeria, the integration of residues from Siamese senna (*Senna siamea*), a leguminous tree, reduced topsoil acidification resulting from repeated applications of urea fertilizer (Vanlauwe et al. 2005).

Adaptation to local conditions

As previously stated, soil fertility status

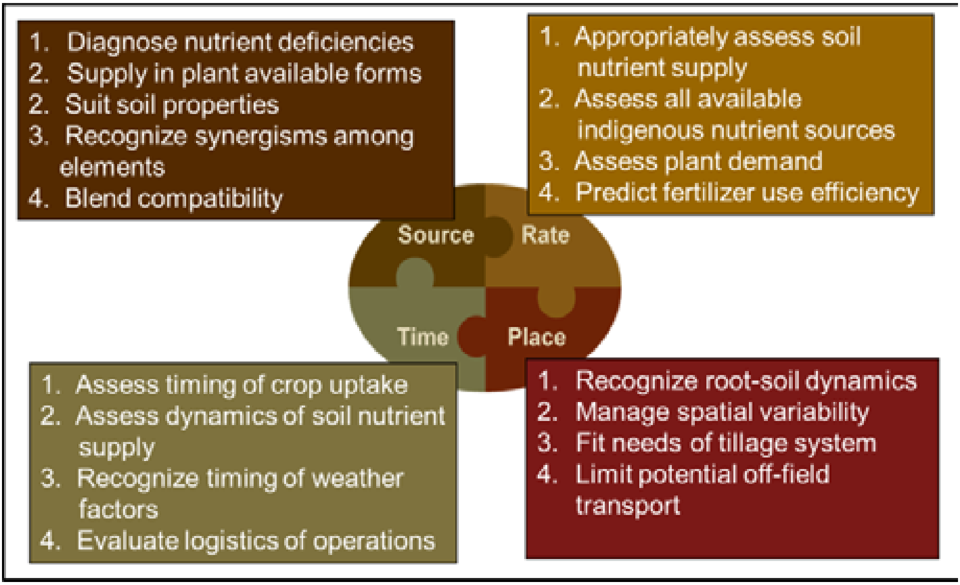

Figure 2. The '4R' Nutrient Stewardship as developed by the International Plant Nutrition Institute, indicating example details of what each 'R' entails. Source: Zingore and Johnston (2013).

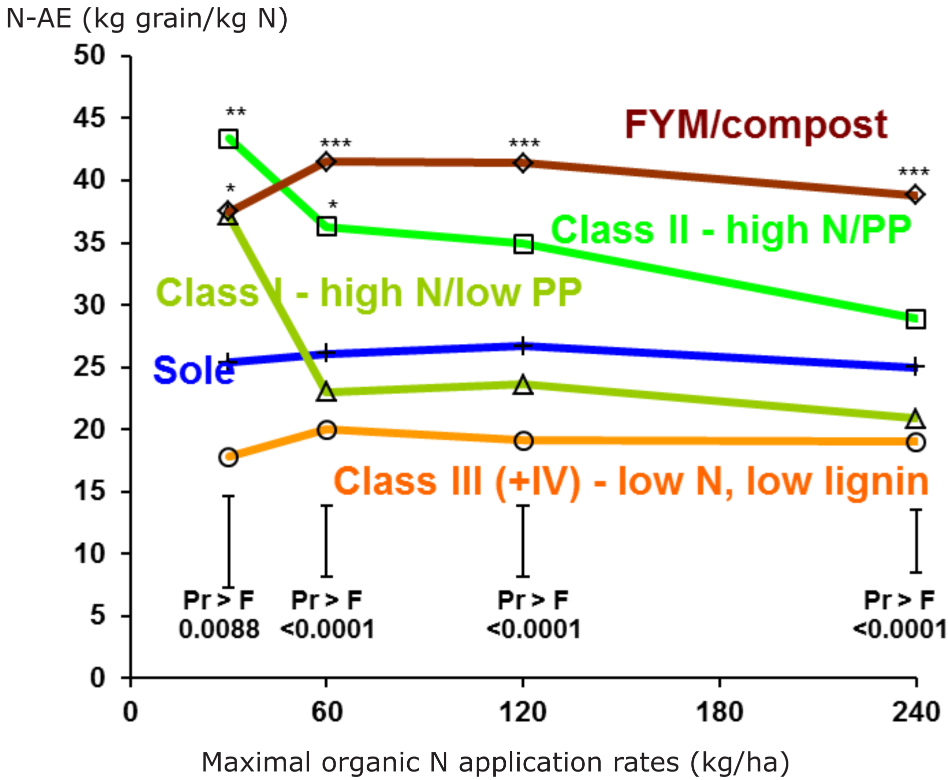

Figure 3. Agronomic efficiency of fertilizer N (N-AE) as affected by combination with different classes of organic inputs (Classes I, II, III, + IV, and manure + compost) for organic N application rates ≤30 kg N/ha (125 observations), ≤60 kg N/ha (238 observations), ≤120 kg N/ha (305 observations), or ≤240 kg N/ha (352 observations). Error bars are average Standard Errors of the Difference. The symbols '', '**', and '***' indicate a significant difference with the sole fertilizer treatment at the 0.1, 1, and 5% levels. In the legend, 'F', 'OI', 'FYM', and 'COM' refer to fertilizer, organic inputs, manure, and compost, respectively. Source: Vanlauwe et al. (2011b).*

can vary considerably between fields within a single farm and between farms with substantial impacts on fertilizer-use efficiency (see photo on next page). In addition to adjustments to fertilizer and organic input management, measures with adaptation to local conditions are needed, such as the application of lime on acid soils, water harvesting techniques on soils susceptible to crusting under semi-arid conditions, or soil erosion control on hillsides, to address other constraints. Lastly, adaptation also includes considering the farming resources available to a specific farming household, often referred to as the farmer's resource endowment, the status of which is related to a specific set of farm typologies. ISFM options available to a specific household will depend on the resource endowment of that household.

A 3-week-old maize crop in two different plots within the same farm (about 200 m apart) in Western Kenya. Both maize crops were planted at the same time and managed in the same way. The left photograph shows a responsive plot near the homestead while the right photograph shows a less-responsive plot with high densities of "couch grass" [Elymus repens (L.) Gould subsp. repens], a noxious weed (see inset). Source: Vanlauwe et al. (2011a).

Towards complete ISFM

Complete ISFM comprises the use of improved germplasm, fertilizer, appropriate organic resource management, and local adaptation. Several intermediate phases have been identified that assist farmers in moving towards complete ISFM, starting from the current average practice of applying 8 kg/ha of fertilizer nutrients to local varieties. Each step is expected to provide the management skills that result in improvements in yield and in AE, with technological complexity increasing towards the right (Fig. 1). Figure 1 is not intended to prioritize interventions but rather suggests a stepwise adoption of the elements of complete ISFM. It does, however, depict key components that lead to better soil fertility management. In areas, for instance, where farmyard manure is targeted towards specific fields within a farm, local adaptation is already taking place, even if no fertilizer is used. This is the situation in much of Central Africa.

Successful uptake of ISFM practices

Several examples can be identified where ISFM has made a difference to smallholder farmers, including (1) dual-purpose grain legume–maize rotations with targeted fertilizer applications pioneered by IITA for the moist savannas (Sanginga et al. 2003) and (2) micro-dose fertilizer applications in legume–sorghum or legume–millet rotations with the retention of crop residues and combined with water harvesting techniques in the semi-arid agroecozone (Tabo et al. 2007).

As for the grain legume–maize rotations, the application of appropriate amounts mainly of P to the legume phase ensures good grain and biomass production. The latter in turn benefits a subsequent maize crop and thus reduces the need for external N fertilizer. Choosing an appropriate legume germplasm with a low harvest index will favor the accumulation of organic matter and N in the plant parts not harvested and choosing adapted maize germplasm will favor a matching demand for nutrients by the maize. Selection of fertilizer application rates based on local knowledge of the initial soil fertility status within these systems would qualify the soil management practices as complete ISFM.

Outlook

In view of the many ongoing investments related to the dissemination of ISFM practices, it is expected that the examples of successful uptake will be amplified over large areas across various farming systems.

The principles underlying ISFM have also been observed to be applicable to cassava-based systems (see other articles in this publication). Notwithstanding the good prospects for impact generated through improved soil management, several technical issues remain to be resolved. These include (1) how farmers can diagnose the soil fertility status of their plots, including non-responsiveness, (2) how ISFM recommendations vary along such within-farm soil fertility gradients, (3) how non-responsive soils can be rehabilitated (or does this not make sense under certain circumstances?), (4) what minimal level of resource endowment is required to engage in ISFM, (5) how ISFM principles can be condensed to a set of easy-to-implement rules of thumb, adapted to a specific cropping environment, (6) whether efficient fertilizer use is a valid entry point towards sustainable intensification, (7) whether ISFM produces sufficient *in-situ* crop residues to ensure that soil carbon values remain about a minimal threshold, (8) what minimal conditions are needed (e.g., population density, policy) to allow large-scale uptake of ISFM, and (9) how ISFM relates to conservation agriculture.

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Climate-smart perennial systems

Laurence Jassogne, l.jassogne@gmail.com, Piet van Asten, Peter Laderach, Alessandro Craparo, Ibrahim Wanyama, Anaclet Nibasumba, and Charles Bielders

Coffee is a major cash crop in the East African highland farming systems. It represents a high proportion of export values at the national level (for example >20% for Uganda). It is also crucial for the sustainability of the livelihoods of smallholder farmers.

During a survey in Uganda, smallholder farmers explained that the income generated by coffee had sent their children to school and helped to build permanent houses. Prices of coffee have also been increasing in the past decennia, motivating them to continue growing the crop.

Although coffee is a promising cash crop, smallholder farmers that grow coffee are still vulnerable. Soil fertility is declining, pest and disease pressure is increasing, populations iare rising, and land is continuously fragmented. Above all, climate change is starting to take its toll and puts further pressure on the coffee-based farming systems—directly, because temperature and rainfall have an impact on the physiology of Arabica coffee, and indirectly because the incidence and severity of certain pests and diseases such as the coffee berry borer and coffee leaf rust will increase.

Banana-coffee system in East Africa. Photo by P. van Asten, IITA.

Current and future suitability of coffee growing areas

In collaboration with Dr Peter Laderach (CIAT), the direct effect of climate change on the suitability of coffee-growing areas in Uganda was mapped (Fig. 1).

Laurence Jassogne, IITA-Uganda; Piet van Asten, IITA-Uganda; Peter Laderach, CIAT, Nicaragua; Alessandro Craparo, University of Witwatersrand, South Africa; Ibrahim Wanyama, IITA-Uganda; Anaclet Nibasumba, IITA-Uganda, Universite Catholique de Louvain-la-Neuve (UCL), Louvain-la-Neuve, Belgium, and Institut des Sciences Agronomiques du Burundi (ISABU), Burundi; and Charles Bielders, UCL.

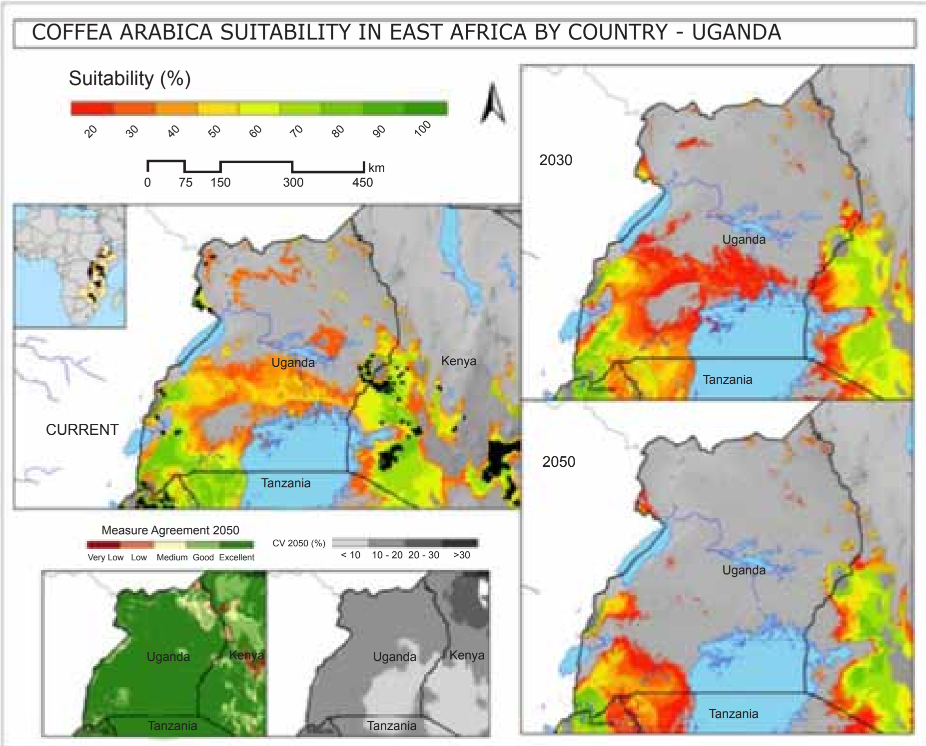

Figure 1. Change of suitability for Arabica-growing areas in Uganda using the MAXENT approach and based on a 'business as usual' climate change scenario.

If the current coffee crop systems do not change (i.e., same coffee varieties and management practices), these areas will move up the slope and the suitable surface area will decrease. In this light, climate-smart coffee-based systems need to be developed to sustain the existing coffee-based systems.

Adaptation strategies in coffee systems

IITA-led field surveys in the region, combined with a literature review, revealed that there is a multitude of coffee systems that exist. This diversity reflects the variability among farmers in terms of their resource availability, objectives, political history, and opportunities (Fig. 2).

Highest yields can be obtained in systems without shade or with low shade levels (Fig. 2). However, these same systems represent higher production risks and a higher use of external inputs. In polyculture systems and forest systems, on the other hand, highest yield quality can be obtained with the minimum use of external inputs. Furthermore, they allow, among others, a better adaptation to climate change, higher carbon stocks, and more ecological services. Quantifying these trade-offs and raising awareness among farmers and other stakeholders

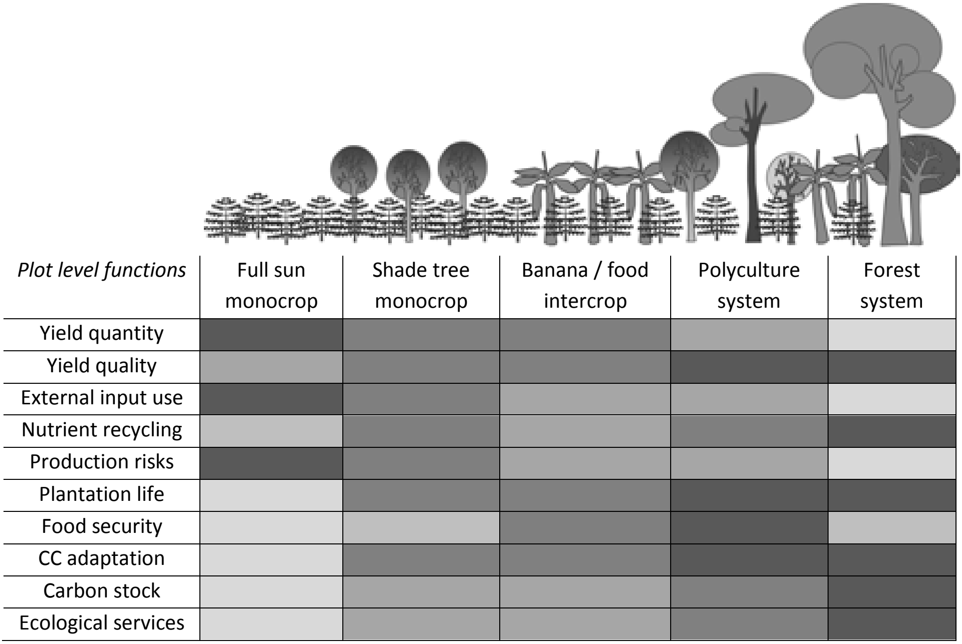

Figure 2. Trade-offs at a farmer-plot level in coffee systems.

along the coffee value chain will help informed and sustainable decisions to be made about the coffee systems.

The more coffee is shaded, the more it is protected from rising temperatures and extreme weather events. Shade in coffee systems can reduce the average temperature in the lower coffee canopy by a few degrees. Although shade is an interesting technology to make coffee systems "climate smart" and hence, adapted to climate change, it is not the primary reason why farmers add shade to their coffee. Shade plants often produce fruit and/or timber. This diversifies the income of the farmer.

The same happens when farmers intercrop coffee with banana. Adding banana to the system increases food security, diversifies income, and adds shading to coffee. A country-wide survey in Uganda showed that coffee/banana intercropping was a common cropping system except in North and North-West Uganda. The incidence of coffee leaf rust was 50% when coffee was intercropped with banana.

Most farmers have some shade trees in their coffee; many practice intercropping with common beans. The combination of short- and long-term benefits of such shade systems makes them ideal climate-smart candidates. Shade trees also sequester carbon, contributing to the mitigation of the effects of climate change. In the end, few farmers (<5%)

have pure full-sun monocropped coffee.

Constraints in diversified systems

However, shade trees also compete with coffee for light, nutrients, and water. If this competition is not managed well, then the shaded coffee system risks collapse, especially in conditions of poor soil fertility. Due to increasing population pressure and land fragmentation, integrated soil fertility management (ISFM) will help to manage nutrient competition. In a shaded system, the turn-over of biomass contributes to nutrient recycling. Organic matter from shade trees or banana will act as *in-situ* mulch. However, soils in Uganda are poor and have some major nutrient deficiencies (Fig. 3).

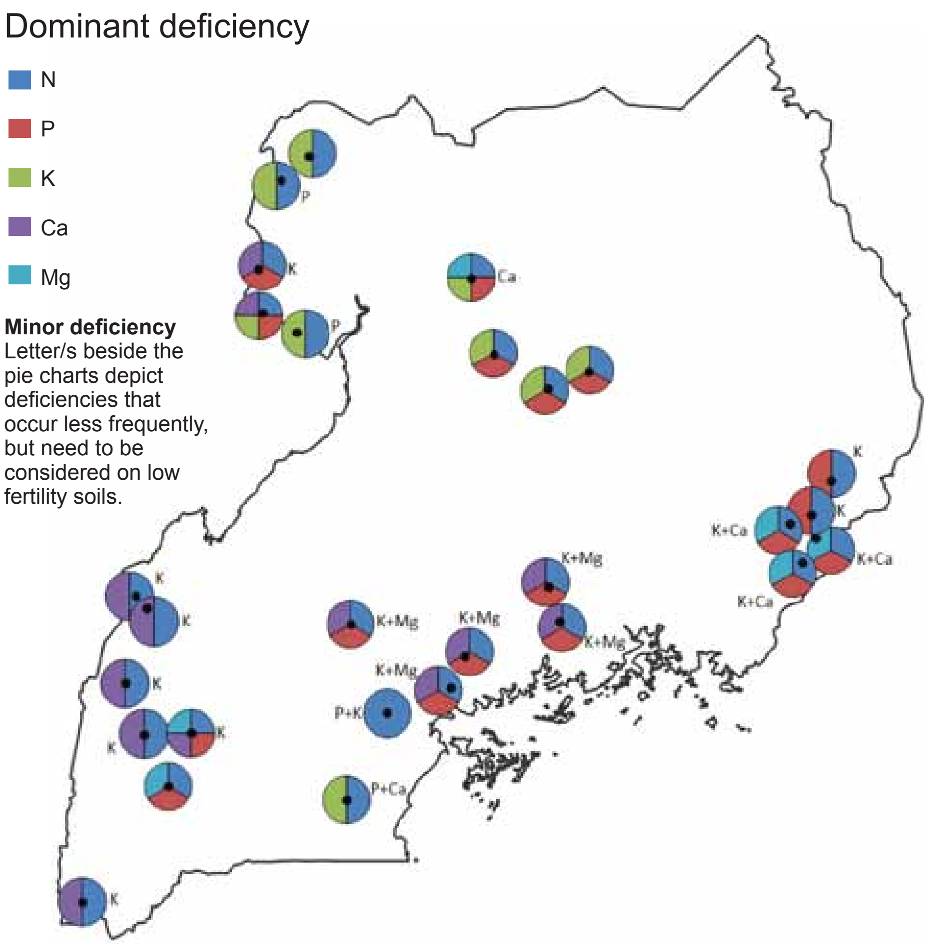

Figure 3. Pie charts depict major nutrient deficiencies based on soil and foliar samples of ten coffee farms per site (black dots).

Banana-coffee systems. Photo by IITA.

Replenishing soil fertility by adding external inputs is necessary if farming systems need to be sustained. Adding small amounts of fertilizers adapted to site-specific deficiencies increases fertilizer use efficiency and forms part of the ISFM approach. Coffee can be a major driver for the adoption of fertilizers by smallholders since farmers are generally organized for access to output markets. The same organizational lines can then be used to provide access to input markets.

Outlook

Understanding the farmers' objectives, perceptions, and constraints is critical in identifying the adoption pathways of production-increasing technologies.

To continue this research, IITA will start a case study in Rakai (Uganda) at a site of the CGIAR Research Program on Climate Change, Agriculture, and Food Security (CCAFS). Here, climate-smart coffee scenarios will be developed in a participatory manner with smallholder farmers, based on data from previous projects, interviews with individual farmers and groups, and farm measurements. Greenhouse gas emissions will be quantified to measure the mitigation potential of the existing coffee systems. Furthermore, fertilizer trials throughout Uganda will be set up to test the site-specific recommendations. IITA also plans to further advance its collaborative research efforts on modeling trade-offs and synergies in coffee smallholder systems in East Africa.

Bridging the grain legume yield gap through agronomy

Robert Abaidoo, r.abaidoo@cgiar.org, Steve Boahen, Anne Turner, and Mahamadi Dianda

IITA and its partners have made significant progress in breeding grain legumes that are high yielding and drought tolerant, and have better disease and pest resistance as well as consumer-preferred traits, such as seed size, texture, and color. The use of these new improved varieties has contributed to increases in productivity on farmers' fields across sub-Saharan Africa.

While crop genetics is very important, the key to bridging the yield gap is to capitalize on the yield potential of a particular genotype and know how to manage it to maximize productivity in challenging environments. This is where the role of an agronomist becomes apparent: to design an integrated management system that reduces the effect of the biotic and abiotic stress factors limiting the productivity of a selected genotype in a given agroecology.

Approach

Several collaborative projects, including N2Africa funded by the Bill & Melinda Gates Foundation through Wageningen University, are developing improved management options to enhance system productivity. The N2Africa project is being implemented in eight countries: DR Congo, Ghana, Kenya, Malawi, Mozambique, Nigeria, Rwanda, and Zimbabwe. It is a research-and-development partnership program that aims to develop, disseminate, and promote appropriate N2-fixation technologies for smallholder farmers, focusing on the major grain legumes. Although atmospheric air contains 78% N2, nitrogen (N) remains the most limiting nutrient for plant growth and also the most limited nutrient in degraded soils.

The good news is that legumes have the unique ability to fix atmospheric N through symbiotic association with root nodule bacteria. The opportunity exists through biological nitrogen fixation (BNF) to improve the yields of legumes in sub-Saharan Africa since current yields

Researcher inspecting cowpea pods. Photo by IITA.

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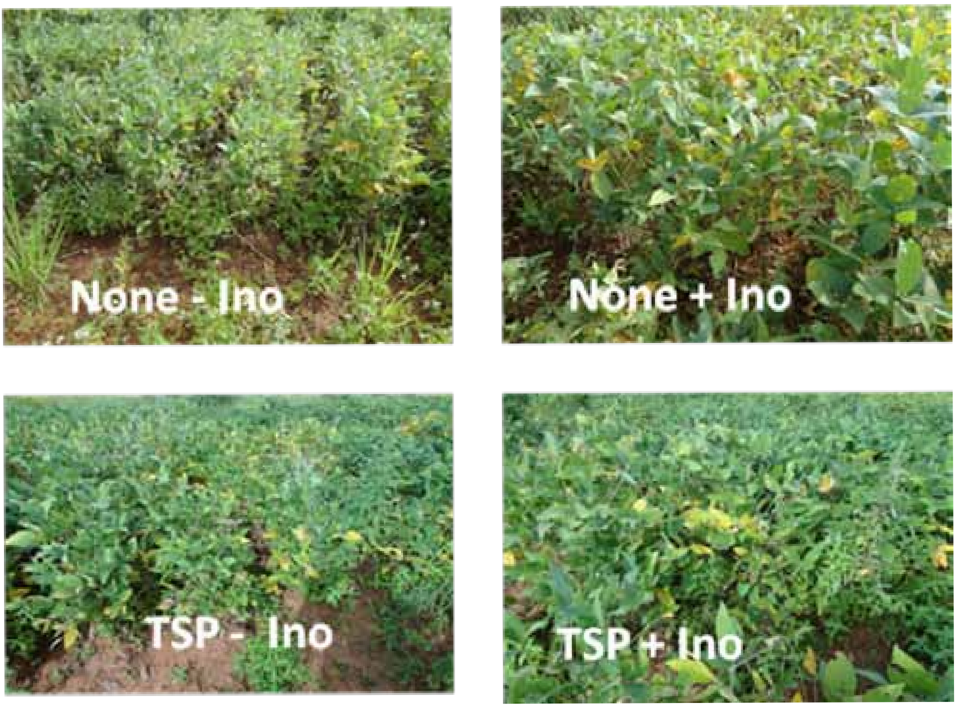
are only a small fraction of their potential. The integration of legumes in cropping systems can benefit associated cereal crops through N-sparing effects, N transfer, and non-N rotation effects. However, the process of BNF can be limited by several biotic and abiotic factors.

Evidence abounds that successful BNF depends on the interaction of environment (climate, rainfall day length, etc.), soil factors (acidity, aluminum toxicity, limiting nutrients), management (use of mineral fertilizers, planting dates and density, weed competition), legume species and variety, and rhizobium species and effectiveness. The current low crop productivity reported in legume-based systems can be attributed in part to the prevalence of these factors that limit BNF. In applying the study to legume-based systems, the N2Africa project expects that the identification of a combination of factors (see photos below), when appropriately managed, will optimize BNF and nutrient cycling in maize-based systems. This ability makes legumes a vital component of smallholder farming systems where the input of N fertilizer is almost negligible. Successful increases in legume productivity will lead to (1) increased availability of major sources of protein for direct consumption by rural households; (2) improved soil health through BNF and a reduced need for inorganic N fertilizers; (3) the breaking of pest and disease cycles of other crops when in



Enhancing biological N through bradyrhizobium inoculation and phosphorus application. Ino = inoculum, TSP = total super phosphate.

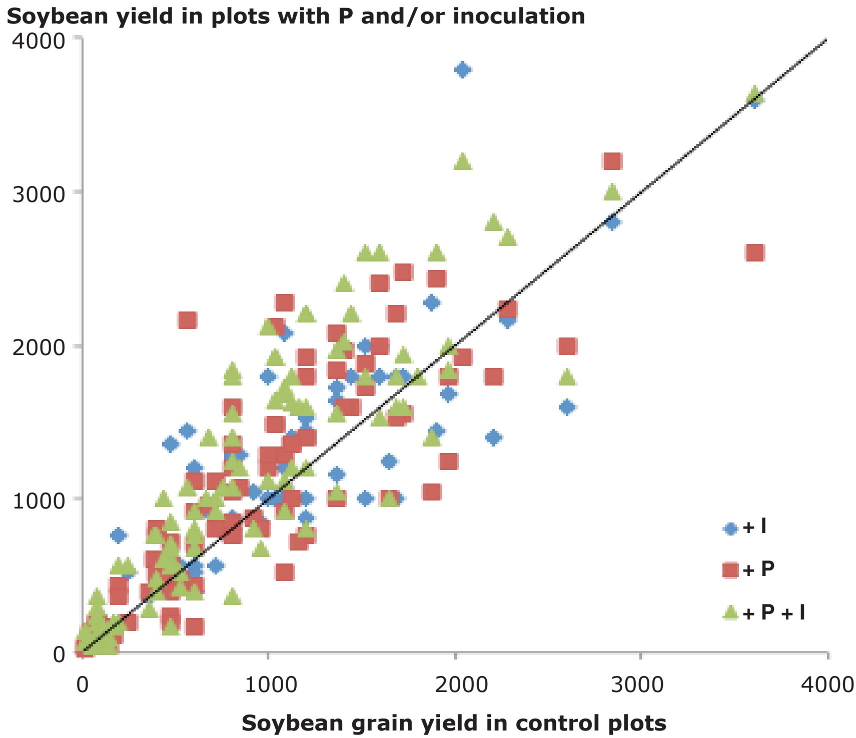


Figure 1. Range of responses to bradyrhizobium inoculation and phosphorus application.

rotation with legumes; and (4) improved income and health for the rural poor.

Preliminary results

In collaboration with the national agricultural research and extension systems (NARES) in the eight countries, the project has isolated several indigenous rhizobia strains, notably in Kenya, Nigeria, Rwanda, and DR Congo, from local farmlands to identify and characterize superior strains for enhanced BNF. The goal is to develop inoculum production capacity using superior native rhizobial strains through collaboration with private sector partners. In addition, several commercial inoculant strains are being evaluated to identify improved varieties with enhanced BNF for integration into specific farming systems. Results of the project have shown that the inoculation of improved soybean varieties resulted in higher yields in several project sites.

However, grain yields may be constrained in P-deficient soils, hence the combined use of P fertilizers and inoculum consistently produced higher yields (Fig. 1). Note from the same figure that responses to inoculants and P fertilizer are highly variable with yield in amended plots ranging from 0 to over 3 t/ha under on-farm conditions. This further stresses the need for local adaptation (see Vanlauwe, page 6) and the need to observe the main factors determining such variability.

Within the N2Africa project, having

detailed monitoring and evaluation (M&E) tools within large-scale adaptation and dissemination field campaigns is an important component of the 'Research in Development' concept, at the core of its learning objectives. Where soil pH and levels of P are not too low, an application of 20 kg P/ha is adequate for the proper growth of soybean, cowpea, and groundnut but in soils deficient in P or with low pH,40 kg/ha is optimum.

Related interventions

The project is also identifying high-yielding legume varieties with varying maturity durations for specific environments to provide farmers with options that will enable them to match varieties to the length of the growing season. For example, when the rain is delayed in a particular year or for some reason farmers delay planting, they can select short-maturing varieties that can fit into the remaining growing period.

A major emphasis is being placed on determining the best time to plant various legumes in several agroecologies in combination with appropriate row spacing and plant population. Planting at the right time enhances yield in many ways: (1) the growing period coincides with good rainfall despite its variability in some years; (2) the crop is exposed to optimum temperature regimes; (3) growth coincides with the optimum solar radiation and daylength that regulate vegetative and reproductive growth phases in legumes due to their photosensitivity; and (4) plants escape the major pests and diseases that limit yield.

Partnership

With project partners which include the national agricultural research and extension systems, nongovernmental organizations, community-based organizations, and farmers' associations, these technologies have been developed into recommended packages and are being demonstrated on-farm. The demonstration plots are established with the direct participation of farmers who are responsible for the day-to-day maintenance to encourage hands-on learning. Field days are also organized during the growing season for individuals and farmers' groups to create awareness about the technologies. The project encourages women's participation as well. Other dissemination activities involve the distribution of inputs to project participants including improved seeds, inoculants, and P fertilizer and lime at agreed prices. The project has developed training programs to improve the skills of extension agents, farmers, and other stakeholders to ensure sustainability of the results after the project ends.

Outlook

It is expected that these agronomic interventions should lead to increased diversification of N2-fixing legume species in smallholder farming systems in sub-Saharan Africa, expansion in the cultivation of grain, greater productivity in legume-based farming systems, and enhanced family incomes and nutrition. In collaboration with microbiologists, plant breeders, and the private sector, the selection and dissemination of efficient rhizobial inoculant strains and improved varieties of grain legumes with enhanced BNF capacities adapted to various environmental stresses will improve the prospects of increasing legume components in cropping systems as well as enhancing the production of expanded ecosystem services.

Soil: nature's Pandora's box

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Soil, a natural resource of overwhelming magnitude, is too often taken for granted, even if its importance is recognized at the highest levels. Franklin Delano Roosevelt, for example, lamented that "The nation that destroys its soil, destroys itself" when reflecting on the USA's dustbowl era.

The "anchor" for the great majority of crops and plants, the soil is a physical support system for crop production and survival. However, it is also a paradoxical Pandora's box of contrasts and opposing forces. As a refuge for pests and diseases capable of broad-scale crop devastation, it acts to harbor the death knell of the very life it supports. The soil-borne bacterium that causes bacterial wilt, *Ralstonia solanacearum*, for instance, can inflict 100% mortality to a field of tomatoes; cysts of some nematode species or spores of certain bacteria can lie dormant in the soil for decades, and then wreak havoc on susceptible crops when stimulated.

By contrast, the soil also acts as a treasure trove of beneficial microorganisms. Some are obligate parasites of crop pests and diseases, others facilitate plant access to nutrients, or enable plants to tolerate

Slash-and-burn forest clearance for crop cultivation in West Africa. Photo by Danny Coyne.

Danny Coyne, Nematologist, IITA-Tanzania.

unfavorable conditions and toxic contaminants. The breadth of microbial biodiversity can also, in effect, be indicative of soil health. The rich tapestry of soil biodiversity involves a highly complex series of interactions, which facilitates biological equilibrium, including the suppression of pests and diseases. Determining how to measure this and relate it to soil health is currently a research topic at IITA. For instance, can a minimum number of non-parasitic nematode genera signify a healthy soil, as suggested by Ferris et al. (2001), and can we rapidly determine this using molecular barcoding? (e.g., Yu et al. 2012).

In Africa, our knowledge of the microbial diversity is particularly sparse and underexplored, and the biological rewards to be reaped vastly underrecognized. At IITA we intend to change this.

Intensifying agriculture in Africa

For Africa to reverse its current trend of declining crop productivity and raise it to a more globally reflective level (Hazel and Wood 2008) intensification of cropping systems is essential (see Vanlauwe this edition). The Asian Green Revolution was successful due to, among other things, the broad-scale use of pesticides to combat pests and diseases. However, their excessive use was a hard lesson learned, and numerous such pesticides are now no longer available.

More ecologically sensitive alternatives are now sought, increasingly so, with soil microbial biodiversity a clear target for exploration. Cropping intensification, however, needs to be carefully managed. The more intensified the system, the greater the selection pressure for pests and disease, and the more severe the problem. The appearance of nematode problems, regularly overlooked and famously misdiagnosed, is an initial indicator of the breakdown of a sustainable system.

At IITA, root-knot nematodes (*Meloidogyne* spp.) are a key focus of attention. With a short life cycle, rapid multiplication rates, broad host range, and scarcity of suitable management options, they pose a particular nuisance and are probably the most important biotic constraint across Africa (Coyne et al. 2009).

Intensification also results in reduced biodiversity, with many microorganisms unable to survive the heightened soil disturbance or a more uniform cropping pattern. At IITA, in collaboration with Basel University (Switzerland), we investigated the effect of cropping intensification on the diversity and occurrence of arbuscular mycorrhizal fungi (AMF) associated with yam (*Dioscorea* spp.) (Tchabi et al. 2008).

Yam is viewed as a nutrient-hungry crop, and thus often planted in more fertile soils following the removal (slash and burn) of forest or long-term fallow, an unsustainable and environmentally detrimental practice. It is also particularly afflicted by parasitic nematodes. AMF needs to attach to and grow on plant roots, forming a special relation which is mostly mutually beneficial, creating enhanced nutrient flow to plants. This relatively small and rather unique study showed that yam is associated with a wide array of AMF species and is highly mycorrhizal. The high diversity and incidence of AMF communities, however, decreased dramatically following the removal of forest and cropping intensification (Fig. 1).

Is there a link therefore between yam nutrient access and AMF? And can we exploit this AMF-yam

	AMF species
South Guinea Savannah	35
North Guinea Savannah	39
South Sudan Savannah	47
Total	**59**

Increasing dryness

Total 8 genera

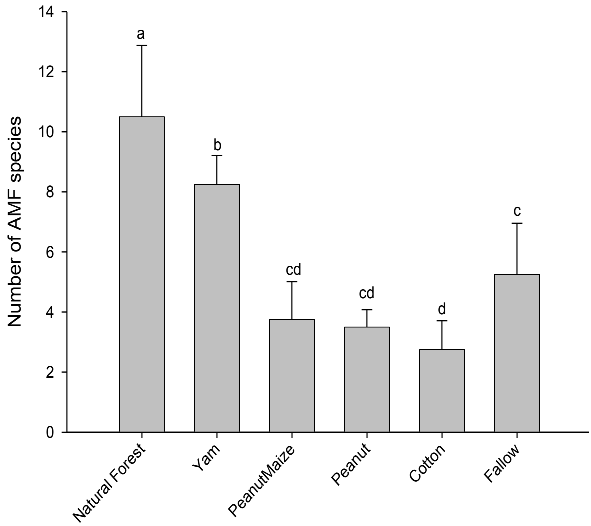

Figure 1. AMF species abundance and diversity in relation to agroecological zones (and relative water availability) in Togo and Benin, West Africa, under varying levels of cropping intensification.

relation to help preserve West African forests? Furthermore, yam tubers were less affected by yam nematodes in the presence of AMF! The limited knowledge of soil microbial diversity in Africa is acutely highlighted with this study, which alone led to four species being newly described and contributed to the revision of the Phylum *Glomeromycetes* (Oehl et al. 2011).

Balancing ecological equilibrium

At IITA we recognize the potential of healthy soils for crop productivity, in addition to the resource potential of beneficial soil microorganisms for use in pest and disease management. While specialists work on diagnostics, establishing economic importance and developing management solutions for soil-borne pests and disease, similar efforts are focused on the beneficial aspects of soil biodiversity and soil health.

We recently discovered, for example, that fungal antagonists isolated directly from *Meloidogyne* spp. eggs were far more effective against these pests than those isolated from the soil (see photo on page 24), as is the usual practice (Affokpon et al., 2011).

Outlook

Our plan is to work towards the identification of biological elements, which enhance crop productivity, as well as specific organisms, such as AMF, nitrogen-fixing bacteria and *Trichoderma* spp., for development as potential products.

As with the pain and suffering that Pandora’s

Opposing forces: a combined inoculation of the beneficial soil micoorganisms Bradyrhizobium japonicum, Glomus mossea, and Trichoderma pseudokoningii provides similar and effective management against root-knot nematodes (Meloidogyne spp.) on soybean as the conventional nematicide Carbofuran.

box in the Greek mythology inflicted upon the world, so can the destructive potential to crops that the soil environment harbors be moderated, providing hope by balancing the ecological equilibrium. IITA strives to harness this equilibrium by understanding the mechanisms of the dynamics of healthy soils and determining the key factors that will help curtail pest and disease development.

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BEST PRACTICE

Best practices for maize production in the West African savannas

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In the past two decades, maize has spread rapidly into the moist savannas of West Africa, replacing traditional cereal crops such as sorghum and millet, particularly in areas with good access to fertilizer inputs and markets.

In the West African moist savannas, higher radiation levels, lower night temperatures, and a reduced incidence of diseases and insect pests have helped to increase maize yield potentials compared with traditional areas for maize cultivation (Kassam et al. 1975). Because of the availability of short-season early maturing varieties, cultivation has gradually spread to the Sudan savanna where the growing period is

Maize is the top staple and cereal crop in sub-Saharan Africa. Photo by IITA.

Alpha Y. Kamara, Savanna Systems Agronomist, IITA-Kano.

Maize plants infested by the parasitic weed Striga. Source: *icipe*.

90–100 days. Despite the expansion in these production areas, maize yields in farmers' fields average from 1 to 2 t/ha in contrast to the higher yields of about 5 to 7 t/ha reported on breeding stations in the region (Fakorede et al. 2003).

Constraints

Maize production in the savannas is faced with several production constraints which limit productivity. Poor soil fertility, drought, and *Striga hermonthica* parasitism combined can reduce on-farm yield by over 70% even with the use of high-yielding varieties. Land-use intensification in the northern Guinea savanna has resulted in serious land degradation and nutrient depletion (Oikeh et al. 2003). Nitrogen (N) is the nutrient most deficient in the soils and it most often limits maize yield (Carsky and Iwuafor 1995). Unfortunately, due to high cost and poor infrastructure, the availability of N fertilizers is limited.

The problem of poor soil fertility in the Guinea savanna is compounded by recurrent drought at various stages of crop growth. For maize, drought at the flowering and grain-filling stages can cause serious yield losses (Grant et al. 1989). This indicates that farmers' fields are rarely characterized by only one biotic stress. It would, therefore, be desirable to increase the tolerance of crops to several stresses that occur in the target environment (Bañziger et al. 1999).

Surveys in the northern Guinea and Sudan savannas of Nigeria showed that *Striga* has remained a serious problem, attacking millet, sorghum, maize, and upland rice (Showemimo et al. 2002). In northern Nigeria, over 85% of fields planted to maize and sorghum were found to be infested (Dugje et al. 2006). Grain yield losses ranged from 10 to 100% for these crops (Oikeh et al. 1996). In addition to the damage from parasitic weeds, significant losses occur in maize if other weeds (grassy and broadleaf) are left to compete freely with the crop.

To maintain a good crop and increase grain yield/unit area, agronomic best practices should be undertaken to address these constraints. Appropriate soil fertility management, drought adaptation, and proper weed management can help to close the yield gap for maize in the West African savannas.

Soil fertility management

Maize is a heavy feeder particularly in terms of mineral N. Because soils in the West African savannas are low in plant nutrients, the crop cannot be grown without the application of some form of mineral and/or organic inputs. Farmers often see a dramatic increase in the response of maize to mineral N. If the fertilizer is applied wrongly, however, use efficiency will be reduced and the benefit will be minimal. For optimum economic yield, we recommend 50 kg/ha each of N, P, and K in the form of NPK 15:15:15 at planting if moisture is sufficient or at one week after planting (WAP), and 50 kg N/ha in the form of urea at 3–4 WAP. Increased use of organic and mineral fertilizers, together with diversification in cropping to include legumes grown in rotation is an important tool in restoring or sustaining soil fertility of the intensifying cropping systems of the dry savannas (Sanginga et al. 2003).

These so-called "balanced nutrient management systems" can be further enhanced through the use of improved cultivars that are drought tolerant and can use available nutrients efficiently, such as maize cultivars developed at IITA. This approach that has come to be known as integrated soil fertility management (ISFM) is not characterized by unique field practices, but is a fresh approach to combining available technologies in ways that preserve soil quality while promoting its productivity (Sanginga et al. 2003).

Agronomic practices for drought adaptation

Agronomic practices that enable farmers to adapt to the effect of mid- and end-of-season drought will increase maize productivity in the West African savannas. Several strategies have been developed for the conservation of soil and water to maintain productivity including rainwater harvesting, live barriers, supplementary irrigation, minimum tillage, mulching, bunded basins, and tree planting (Drechsel et al. 2004).

A central approach to increasing crop production in the dry savannas is the planting of well-adapted cultivars at the optimum date. The short growing season and frequent droughts require early and extra-early maturing crop cultivars with drought tolerance. Late- and medium-maturing cultivars, should also be drought tolerant and planted by mid-June after the rains have established. Breeders at IITA and partner institutions have developed cultivars that are early maturing, tolerant of drought, high temperatures, and low contents of soil nutrients and resistant to pests and diseases. These early maturing cultivars can be planted between mid-June and 25 July in the Guinea savannas and between the first week of July and mid-July in the Sudan savanna.

Weed management

Different approaches are recommended in managing parasitic weeds on the one hand and grassy and broadleaf weeds on the other. An integrated approach is recommended for the control of parasitic weeds. Because *Striga* attacks the plant underground and causes damage

Striga management technologies. Source: *icipe*.

before emergence on the host, the use of postemergence herbicides and hand pulling cannot be recommended. Damage in maize can be reduced by growing varieties that are tolerant of or resistant to *Striga* or by planting trap crops such as varieties of groundnut (*Arachis hypogaea*), soybean (*Glycine max*), cowpea (*Vigna unguiculata*), and sesame (*Sesamum indicum*) that stimulate the *Striga* seeds to germinate without providing a viable host (Carsky et al. 2000).

Some studies have shown that applying N fertilizer reduces *Striga* emergence and numbers, and boosts cereal grain yield (Showemimo et al. 2002; Kamara et al. 2009). Applying N fertilizer may not be feasible as a stand-alone solution to managing *Striga* in maize because of the high cost but the combined use of N fertilizer and *Striga*-tolerant/resistant varieties has shown promise in the West African savannas (Showemimo et al. 2002; Kamara et al. 2009). However, control is most effective if a range of practices is combined into a program of integrated *Striga* control (ISC) that can provide sustainable control over a wide range of biophysical and socioeconomic environments. Ellis-Jones et al. (2004) showed that growing *Striga*-resistant maize after a soybean trap crop more than doubled economic returns compared with continuous cropping with local (nonresistant) maize. Kamara et al. (2008) showed that these practices reduced *Striga* infestation and damage on farmers' fields and increased productivity by more than 200%.

Although manual weeding is an age-old practice in West Africa, it is no longer sustainable because of high labor costs and the aging farming population. Judicious use of herbicides is recommended to control weeds effectively and increase maize productivity. We normally recommend the use of postemergence herbicides to kill weeds before land preparation and planting. Two common types are Glyphosate and Paraquat. Glyphosate (Round-up, Glycel, Force-up) is usually strictly applied before planting, whereas Paraquat (Gramazone) can be mixed with Pendimenthalin (Stomp, Pendilin) and applied immediately after planting. Paraquat kills any live weeds in the field; Pendimenthalin kills preemerging weeds.

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Boosting the productivity of cassava-based systems in DR Congo

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The intensification of African agriculture is an essential response to the increasing demands for more food without endangering important natural resources, including the forests in the Congo basin.

Because of its potential to produce some roots, cassava is often considered a crop that “likes” poor soils but, as all other crops, it responds to and requires a sufficient amount of nutrients to produce attainable yields. The transformation of cassava from a food security to a cash crop in many countries in Africa further stresses the need for nutrient replenishment strategies in cassava-based systems since the transport of cassava roots to processing plants can accelerate the amount of nutrients exported from the farm.

In recent years, integrated soil fertility management (ISFM) (see article on page 6 of this publication) has been accepted by many organizations as the underlying technical framework for the sustainable intensification of smallholder systems in Africa. This article highlights the progress of work on the application of ISFM principles in the context of cassava-based systems in DR Congo.

Current situation

In the highlands of Sud-Kivu province, cassava and common beans are among the main food crops traditionally cultivated in mixed cropping systems. Cassava monocropping is done only in marginal fields where other crops fail to yield. Farmers generally allocate about 0.2–0.3 ha (30–45% of their farm area) to cassava–legume intercropping and obtain average yields of 400–800 kg/ha of legume grains and 10–15 t/ha of cassava fresh roots. Pressure on land is very heavy due to high population densities and justifies agricultural intensification and investment in soil productivity.

In Bas-Congo province, on the other hand, farmers practice slash-and-burn agriculture. Cassava is grown

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for 1 or 2 years, followed by fallow periods of 2 to 4 years. In the past two decennia, the population has grown by more than 50% leading to more demands for food, especially from nearby Kinshasa. Improved and sustainable, fire-free production systems are urgently needed. In DR Congo, most farmers have no access to improved varieties and have very limited options to improve soil fertility.

Fertilizer and germplasm

First, the use of improved, pest- and disease-resistant varieties in combination with appropriate rates of NPK fertilizer was observed to result in a 30–160% increase in cassava root yields in eastern DR Congo. A visible increase was observed in yields of the stems, important for the production of planting material (photo). In western DR Congo, cassava yields doubled from 12 to 25 t/ha with the application of moderate rates of NPK and reached over 40 t/ha with higher rates. Several initiatives are taking place to ensure that large quantities of planting materials reach smallholder farmers with specific attention being given to those varieties resistant to cassava mosaic disease and the brown streak virus.

Combined application of fertilizer and organic inputs

Fertilizer response and the effect of combining inorganic and organic nutrient resources were also evaluated on cassava systems. The most common fertilizer, NPK 17:17:17, was applied in western DR Congo with or without green manure made from *Tithonia* sp. or *Chromolaena* sp., and the effects on storage root yield were evaluated in two locations with a differing

Control (no inputs) NPK applied at 2 bags/ha

In the DR Congo, application of 2 bags of NPK fertilizer/ha results in root yield increases from 30 to 160%.

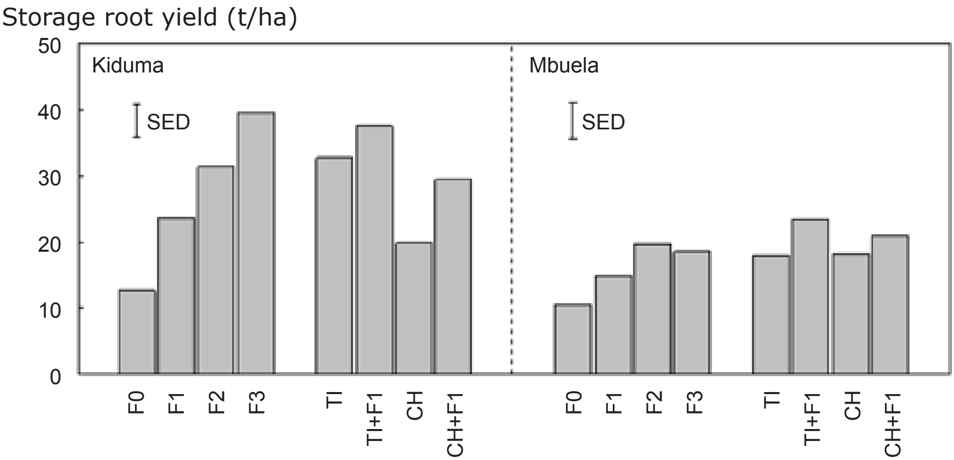

Figure 1. Cassava storage root yields as affected by applying compound fertilizer (17 nitrogen: 17 phosphorus: 17 potassium) at rates of 0 (F0), 40 (F1), 120 (F2), and 200 (F3) kg K/ha, and green manure (TI = Tithonia sp.; CH = Chromolaena sp.) at 2.5 t dry matter/ha alone or together with compound fertilizer at 40 kg K/ha in two trial locations in Bas-Congo, Democratic Republic of the Congo. SED: standard error of difference at P<0.05. Source: Adapted from Pypers et al. (2012).

soil fertility status (Fig. 1). Both plants are commonly found in fallow vegetation in western DR Congo. Control yields were similar at the two sites (12 t/ha), but the response to fertilizer differed between the sites: storage root yields reached 40 t/ha at Kiduma but only 20 t/ha at Mbuela with the addition of 200 kg K/ha. A much larger response to *Tithonia* sp. green manure was also observed at Kiduma, which was likely to have been related to the higher quality and nutrient contents of the green manure grown at that site.

Combining organic and inorganic nutrient resources did not result in positive interactions. No significant differences were observed between the yields after the sole application of either fertilizer or green manure to the control and those obtained with the combined application of both nutrient sources (Pypers et al. 2012). In maize-based systems, positive interactions between organic and inorganic fertilizers often arise from better synchrony in N release and N uptake by the crop. In cassava systems, where K is more often the most limiting nutrient, such a mechanism is likely to be less relevant.

In eastern DR Congo, the use of improved germplasm did not result in yield increases without the simultaneous implementation of other ISFM components. Modifying the crop arrangement by planting cassava at 2 m between rows and 0.5 m within the row, intercropped with four legume lines, increased bean yields during the first season and permitted a second bean intercrop. This can also increase the total legume production by up to 1 t/ha and resulted in additional revenues of almost $1000/ha (photo). The crop arrangement or

1st legume: groundnut
(2 months after planting)

2nd legume: climbing bean
(6 months after planting)

In the highlands of eastern DR Congo, alternative spacing of cassava (2 × 0.5 m instead of 1 × 1 m) allows the integration of four lines of legumes during one season and two lines of legumes during the second season without affecting cassava densities and yields.

a second legume intercrop did not affect cassava root yields. Fertilizer application increased both legume and cassava yields, and net revenue by \$400–700/ha with a marginal rate of return of 1.6–2.7. Replacing the common bean intercrop by groundnut increased net revenue by \$200–400/ha, partly because of the higher market value of the grains, but mostly due to a positive effect on yield of cassava storage roots. Soybean affected cassava yields negatively because of its high biomass production and long maturity period; modifications are needed to integrate a soybean intercrop into the system.

Local adaptation

Due to the high variability in soil fertility status, the varying landscape features, and the variation in access to inputs, local adaptation is required to ensure that the investments made by cassava-producing households result in the highest returns, in line with the resources (e.g., cash, land, labor) that these households have (see photo below). Such adaptation efforts are best led by extension

Bas-Congo

Sud-Kivu

Cassava land preparation varies widely in DR Congo, partly affected by the slope and water status of the land.

and development partners that have the required skills and capacity to implement such efforts at scale. In eastern DR Congo, erosion is the most urgent issue to be tackled to enhance the sustainability of cassava-based systems. Results from Southeast Asia with the use of live hedges should be explored for these environments.

Outlook

These findings demonstrate the large potential of ISFM to increase productivity in cassava–legume systems in DR Congo. This is crucial in view of the fact that cassava is changing from being almost only a food security crop to one for which there is high demand in local and urban markets. The intensification of production is thus a prerequisite for sustaining cassava-producing households and ISFM can assist in achieving such benefits. However, these benefits were not observed in all study sites. In poor soils, productivity increases were variable or absent, and soil amendments are required. Better targeting and local adaptation of the technologies are possible with a better understanding of the conditions under which positive effects occur.

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12th Plant Virology Symposium

(http://www.iita.org/IPVE)

28 January–1 February 2013, Arusha, Tanzania
Theme: *Evolution, Ecology, and Control of Plant Viruses*

The symposium, held under the auspices of the International Committee on Plant Virus Epidemiology (www.isppweb.org/ICPVE/) of the International Society of Plant Pathology, provides a forum for the exchange of the latest knowledge on emergence, epidemiology, and control of native and newly encountered viruses.

The symposium will hold a special Africa focus session to develop a strategy to combat emerging and reemerging plant virus diseases in sub-Saharan Africa.

Natural resource management in cassava and yam production systems

Stefan Hauser, s.hauser@cgiar.org

Why are yields of cassava in Thailand and India three times higher than in Africa and production costs in Brazil only one-third of those here? Although Africa suffered from the Cassava Mosaic Disease pandemic and currently faces the threat of Cassava Brown Streak Disease, breeding tolerant and resistant germplasm has contributed to yield gains over the last three decades. Thailand, India, and Brazil have been successful in commercial cassava production with yields between 25 and 40 t/ha. The question arises: how can African farmers realize more of the >80 t/ha yield potential of cassava?

Natural resource management (NRM), agronomy, and crop husbandry have hardly ever been credited with "breakthrough" solutions to hunger and poverty. However, when more than 50-75% of the cassava yield potential is not being realized, major improvements are clearly possible through NRM, agronomy, and appropriate crop husbandry.

Cassava has the potential to produce roots even under poor soil conditions. Photo by IITA.

Agronomy and crop husbandry

For West Africa there is still a dearth of agronomic information on cassava. Currently a density of 10,000 plants/ha is the standard, while further increases are being recommended without concrete data on the yield responses to increased density by different growth types. Cassava varieties vary widely in their branching height and level of ramification, leading to different levels of ground cover by single plants and of the start and intensity of intra-specific competition. Cassava yield distribution within the same variety is highly biased (Fig. 1), raising questions on the optimum plant density and issues such as genetic uniformity and crop responses to edaphic (soil) factors.

One future effort will be to determine optimum plant densities for monocrops by major cassava growth types.

Intercropping cassava with maize or grain legumes is still widely practiced and needs to be

Stefan Hauser, Systems Agronomist and CRP Leader, Humidtropics, IITA-Ibadan.

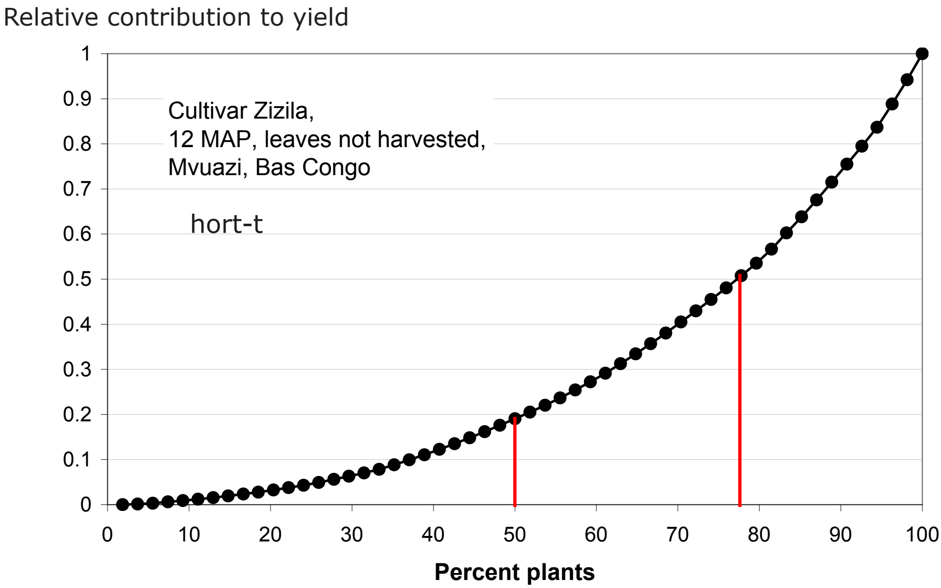

Figure 1. Relative contribution to the yield of individual plants of the cassava variety Zizila in DR Congo planted at 1 × 1 m (10,000/ha). Edible root mass was 87.7% of total mass, fresh edible root yield was 11.56 t/ha. Vertical bar at 50% plants indicate the yield contribution of half the plants to total yield (here <20%), vertical bar at 78% plants indicate the proportion of the population contributing 50% of the total yield. (Source: Hauser et al. 2011, unpublished)

improved. The short-term intercrops are cleared from the field, leaving space unused that can be invaded by weeds, thus there needs to be a follow-up either with weed control or a second crop to occupy the open space. Various crops will be tested for their capacity to perform between developed cassava plants and their contribution to total system productivity.

Weed control remains a problem as there are no postemergence herbicides that cassava would tolerate. Combinations of preemergence herbicides with appropriate planting techniques have the potential to reduce weed competition and labor. For instance, a preemergence herbicide can be applied before planting cassava. The herbicide kills germinating seeds as they break through the herbicide-sealed soil surface. The cassava stakes need to be planted in a vertical position and the orientation needs to be correct so that no emerging cassava leaves touch the soil surface. Such technologies combined with the follow-up use of postemergence herbicides with shields can drastically reduce labor and increase productivity as weeding can be done at the most efficient time.

Fertilizer

Fertilizer use is low in Africa yet it appears certain that fertilizer or other forms of soil nutrient replenishment can contribute to yield increases, higher farm incomes, possibly to lower consumer prices, and thus to better livelihoods. Using average nutrient uptake into all cassava plant parts (dry matter basis) of 6.2 kg N/t, 1 kg P/t, and 5.3 kg K/t, a total supply of 165–25–145 kg N-P-K/ha is required to attain 50% of the current potential yield (45 t/ha fresh roots). Such amounts are unlikely to be supplied by the soil and thus nutrient supply is a crucial factor in achieving higher cassava yields.

There are no recent fertilizer response curves for cassava and yam in West Africa, hence, farmers do not know the composition and amounts of fertilizer to apply. The nutrient(s) most limiting to cassava production have not been quantitatively determined. The replenishment of any most limiting nutrient would lead to substantial yield increases. Depending on the limiting nutrient, productivity and profitability increases may be possible at a very low cost and risk. IITA uses a stepwise approach, first determining the most limiting nutrient(s) followed by elaborating the optimum quantity required and the construction of recommendations for optimal nutrient composition and quantities. IITA is currently working with the International Fertilizer Development Center on testing special fertilizer blends for cassava, addressing the augmentation of neglected nutrients such as sulfur, magnesium, zinc, and boron.

Use of other nutrient sources

Compost, manure, mulch, and rock phosphate have all been proposed as means to improve soil nutrient status and crop production. However, none of these sources has had a major impact as farmers need land to produce biomass or else infrastructure is required to mine, process, and distribute rock phosphate. Although the biological sources are important, constraints in biomass production need to be overcome first.

Mineral fertilizers alone cannot sustain crop production on degraded land. Soil organic matter and soil micro-, meso-, and macro-fauna are important in maintaining soil quality and health. Traditionally, fallow phases between crops were replenishing the soils' production capacity. With increased population densities, fallow phases have been shortened or no longer exist. Thus, soils do not recover but continue to lose their production potential. Farmers do not seem to invest in soil fertility but look for ways of coping with ever less fertile soils, thereby degrading them to a stage where cropping becomes unprofitable.

Such situations have been encountered in southern Bénin. Soil fertility and quality management techniques, such as cover crops, manure application, or any other form of organic matter and nutrient recycling have not been adopted at larger scales. In retrospect, there have been constraints to the adoption that were not considered in the process of technological development. Today, with more options available and a stronger and earlier involvement of farmers in research for development, such approaches are worth reconsidering. One such technology, using leguminous cover crops, had little if any success in cassava (Fig. 2).

Controlling the cover crop was a major problem. Consequently IITA works today on efficient and effective control methods. *Pueraria phaseoloides* was introduced to smallholders in southern Cameroon

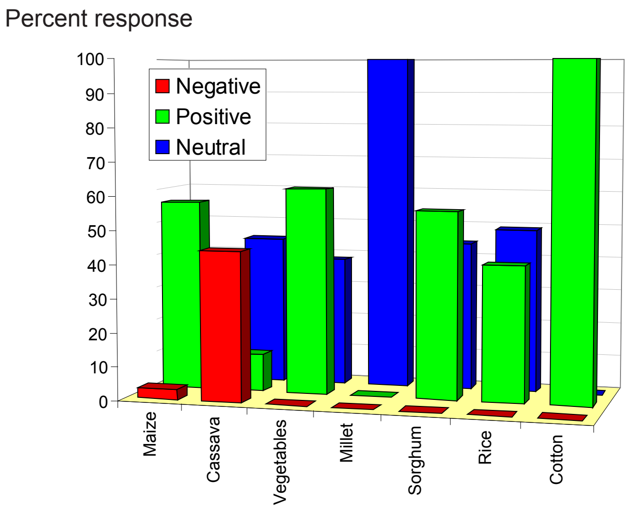

Figure 2. Crop yield response to planted herbaceous fallow in West and Central Africa. Compilation of 396 comparisons from published experiments. Source: Hauser et al. (2006).

but it was not readily accepted as farmers immediately identified it as an aggressive weed, able to destroy crops. However, two years into the use of *Pueraria*, fallow farmers noticed that the weeds most difficult to control had disappeared and that it was easier to clear *Pueraria* than the natural fallow. Some farmers burned the *Pueraria* only to find the land ready to crop without major labor input. Yields of cassava, maize, and groundnut were generally higher after *Pueraria*, whereby the labor-saving burning produced the highest yields (Fig. 3).

Considering farmers' needs *Pueraria* was introduced for soil fertility replenishment but was adopted for its labor-saving effects. Soil fertility was not perceived as a problem and thus positive effects on the soil could be compromised (by burning) without compromising yields. Effects such as weed suppression and the reduction of soil-borne pests and diseases may contribute to the yield increases after *Pueraria*.

Livestock integration and the search for synergies

Few farmers adopted the use of green manures for soil fertility improvement because they have no direct benefits from it. Herbaceous legumes have rarely been used to feed livestock, although there is (anecdotal) evidence that livestock feed on them and that they are beneficial to growth and reproduction. In the IITA-led CRP on Humidtropics, livestock integration will be a major aspect. It will add value to green manure species when these are used to feed livestock that will also benefit from the canopies of root and tuber crops (cassava leaves) remaining at root harvest. Thus, there will be an increase in returns of animal manure to fields, and to crop yields through the combined use of green and animal manures for improved food security and farm incomes.

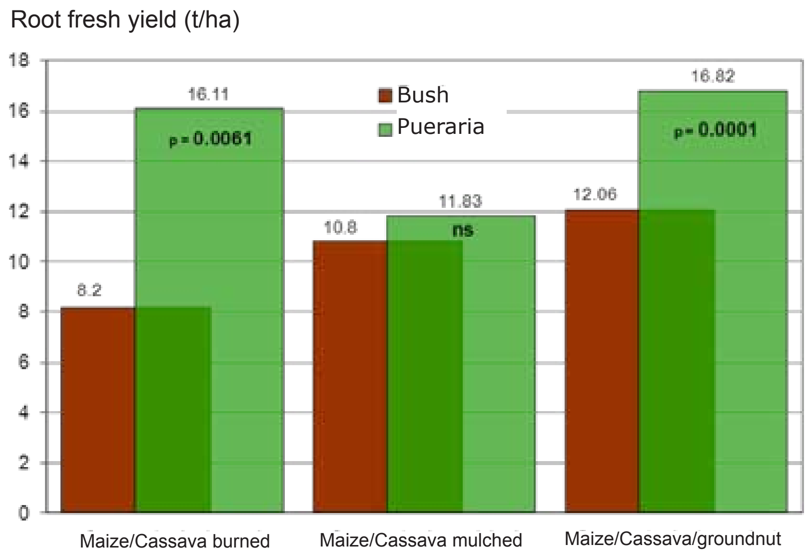

Figure 3. Cassava fresh root yield in burned and mulched maize/cassava and burned maize/cassava/groundnut intercrop after two years of natural bush or Pueraria phaseoloides fallow. On-farm, southern Cameroon, 2010-2011 (Source: Hauser, unpublished)

Outlook

Efficient combinations of agronomic practices, nutrient supply, and soil management practices will be developed to increase the productivity of cassava and yam while improving the status of the natural resource base. Synergistic effects between these measures and the integration of livestock or fish farming will increase resource use efficiency and income generation as well as the quality of the farm food supplies. Due consideration of social and gender aspects in farm household operations will identify the entry point best suited for IITA's interventions. Farmers' feedback and innovations will be integrated into approaches on sustainable intensification to increase food production and improve rural livelihoods while enhancing the capacity of the agroecosystems to deliver essential services.

Cow grazing on Canavalia brasiliensis intercropped with maize, Nicaragua. Source: Rein van der Hoek.

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Integrated soil fertility management for banana systems

Piet van Asten, p.vanasten@cgiar.org, Severine Delstanche, Lydia Wairegi, Tony Muliele, Syldie Bizimana, Godfrey Taulia, Ken Giller, Peter Leffelaar, Laurence Jassogne, Philippe Baret, and Charles Bielders

Banana is the primary food crop in the Great Lakes Region, providing food and income for over 85% of the population. Unfortunately, current banana yields of 5–30 t/ha/year are low compared to potential yields of over 70 t/ha/year. Although between 25% and 70% of this yield gap can be explained by low soil fertility (Fig. 1), the use of external inputs such as fertilizers is virtually nonexistent and soil fertility is mostly managed by recycling local organic residues.

A study done by Severine Delstanche at the Catholic University of Louvain-la-Neuve (UCL) showed that very little nutrients were released from the soil through weathering of the soil minerals (Fig. 2). Hence, soil

Banana systems in Rwanda. Photo by Piet van Asten.

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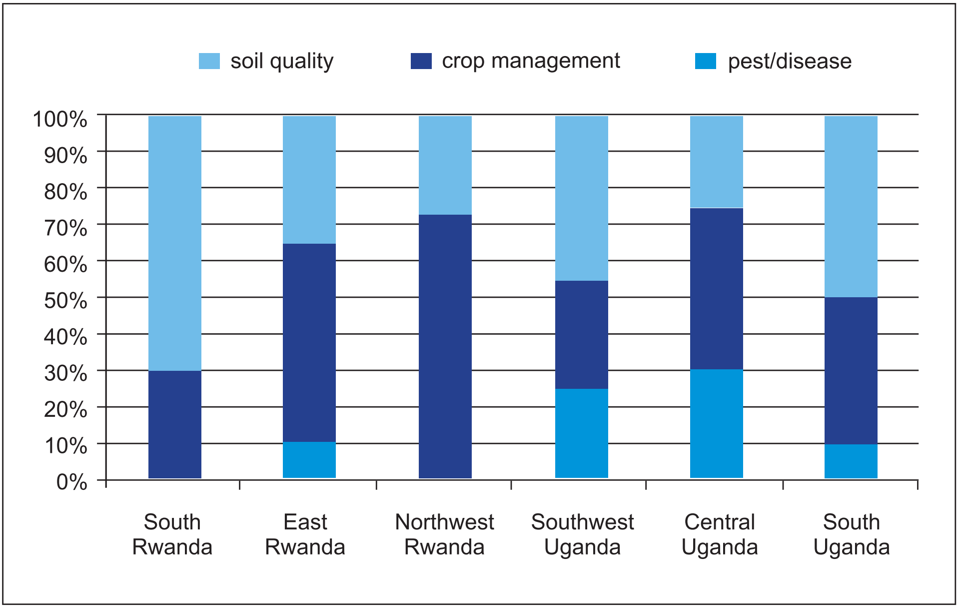


Figure 1. Primary crop constraints as identified by the use of the boundary line approach; adapted from Wairegi (2010) and Delstanche (2011).

fertility depended almost entirely on the soil's organic matter content. In banana-based farming systems, nutrient recycling is very important, as the harvest index is relatively small (<30%). This helps maintain relatively high organic matter content in the soil.

Furthermore, the large and perennial canopy and root system of banana help protect the soil from erosion. Banana therefore plays an important role in protecting the environment in this hilly landscape.

In addition to being an important component in sustaining soil fertility, banana plays an important socioeconomic buffer role for the smallholders. The crop provides food security as bunches are harvested throughout the year and any surplus can be sold to generate a continuous cash flow.

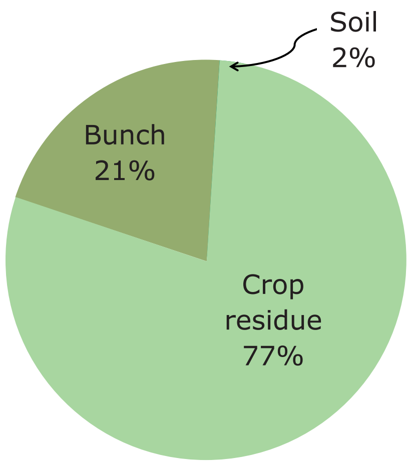
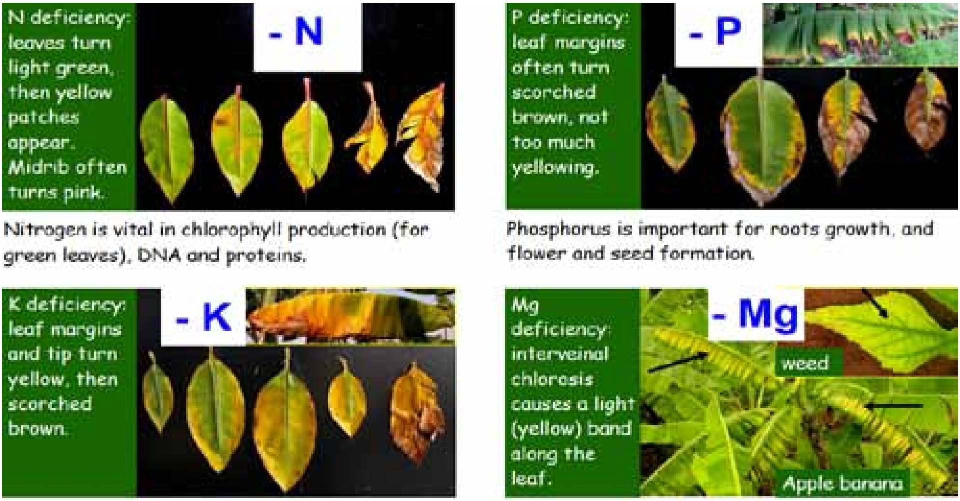


Figure 2. The proportion of annual K fluxes in the banana systems originating from soil mineral weathering (2%), crop residues (77%), and the crop harvest (21%).

Banana systems particularly occur in areas with high population pressure and small (<2 ha) farm sizes. A study by Lydia Wairegi at Makerere University (Uganda), showed that fertilizer use was very profitable in the peri-urban area close to Kampala with marginal rates of return sometimes exceeding 500%. However, in areas far from the market (>150 km), the intensification process seemed less promising, but banana continues to play an important buffer role to maintain food security and protect the environment. In these remote locations, it seems wiser to invest in improved use of local (nutrient) resources, than to purchase mineral fertilizers.

To maintain its buffer role, banana can be integrated with other crops such as coffee and beans. The Ph.D. studies of Tony Muliele and Syldie Bizimana (both UCL) showed that intercropping beans with banana could be improved. Traditionally, farmers in Rwanda, Burundi, and DR Congo would till the banana field at the beginning of the wet season to suppress weeds and prepare the land for bean intercropping. Unfortunately, this practice damages a large proportion of the superficial root system of banana plants. Based on practices observed in Southwest Uganda, a technology of zero-tillage and mulching was tested. Beans are planted in the mulch. The planting holes for the beans were made using a stick. The use of external mulch greatly improved banana performance in eight trials across the region. However, beans did suffer some setback in some instances when the improved banana growth would lead to a more dense canopy, outshading the

Banana trials. Photo by IITA.



Farmers can use pictures to diagnose nutrient deficiencies as shown above for nitrogen, phosphorus, potassium, and magnesium.

understory beans. In collaboration with Bioversity International and the Tropical Soil Biology and Fertility Institute of CIAT (TSBF-CIAT), a series of trials was conducted to reduce the banana canopy through leaf pruning. The results are almost ready, but they provide farmers with advice on how to best manage the trade-offs between banana and the understory legumes.

To improve fertilizer use efficiency and profitability, it will be important for farmers to apply the right nutrients at appropriate rates. To enable the identification of the most deficient nutrients (photo above) that need primary attention when applying fertilizers, compositional nutrient diagnosis (CND norms) were developed by Lydia Wairegi in Uganda and by Severine Delstanche in Rwanda. The CND norms are based on foliar analysis and allow a quick assessment of nutrient deficiencies observed within the plant. Contrary to critical norms for single nutrients, the CND allows for an integrated assessment of nutrient imbalances within the plant.

Besides developing fertilizer recommendations based on foliar analysis, IITA conducted a series of large nutrient omission trials in central and southwest Uganda. Based on the quantification of nutrient uptake, soil nutrient supply, and crop response, a QUEFTS model was developed to predict fertilizer requirements in collaboration with Wageningen University (WUR). This work was led by Ph.D. student Kenneth Nyombi and is currently being carried forward by Ph.D. student Godfrey Taulya. He observed that potassium nutrition was particularly important for banana to alleviate drought stress. The result from the ongoing research effort clearly shows that strong synergies can be achieved when integrating soil fertility, agronomic, and economic research approaches at the plot, farm, and regional levels.

TOOL BOX

Cocoa and REDD

James Gockowski, j.gockowski@cgiar.org, Valentina Robiglio, Sander Muilerman, Nana Fredua Agyeman, and Richard Asare

Smallholder farmers produce improved cocoa planting materials, Côte d'Ivoire. Photo by IITA.

In the humid lowlands of Africa, the expansion of extensive low-input agriculture is the most important driver of tropical deforestation and forest degradation with a negative impact on biodiversity and climate change (Norris et al. 2010; Phalan et al. 2011).

A recent global analysis of the climate change impact of agriculture estimated that between 8.64 and 15.1 million km^2 of land were spared from the plow as a result of yield gains achieved since 1961 (Burney et al. 2010). These land savings generated avoided greenhouse gas (GHG) emissions representing between 18% and 34% of the total 478 GtC emitted by humans between 1850 and 2005. A similar land use change analysis conducted for West Africa estimated that over 21,000 km^2 of deforestation/

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forest degradation that occurred between 1988 and 2007 could have been avoided if the improved seeds/fertilizer already developed in the 1960s had been adopted (Gockowski and Sonwa 2011).

A methodology for quantifying and qualifying the impact of agricultural intensification on deforestation and poverty has been developed. This is based upon (a) the remote sensing analysis of land use change, (b) structured interviews with a random sample of rural households, and (c) an anthropological case study, all conducted in a defined benchmark area. The 1201 km^2 benchmark in the Bia district, Ghana, is the most important cocoa-growing area in the country whose increasingly diminished forests are home to the endangered Roloway monkey (see photo) and are a global conservation priority. Cocoa producers in this benchmark have experienced rapid yield gains as a result of a sequential series of intensification policies that began in 2003.

Measuring deforestation and land use intensification

The retrospective household survey chronicled the land-use and migration history of each household in establishing a mean rate of deforestation from 1960 to 2003. More recent estimates were determined from the interpretation of satellite imagery from 2003 Landsat, 2006 Spot, and 2011 ALOS. Based on these analyses, the mean average rate of deforestation has fallen from 1,006 ha/year prior to the initiation of intensification policies to 212 ha/year.

Most of the deforestation still occurring has entailed encroachments in the Bia Game Reserve and the Krokosua Hills Forest Reserve and, to a lesser degree, Bia National Park whose environs are more stringently protected (Fig. 1). Outside these reserves there is scarcely any forest remaining.

The Roloway monkey (Cercopithecus roloway) is found only in the forests of southeastern Côte d'Ivoire and western Ghana and is listed among the most endangered primates. Source: Unknown.

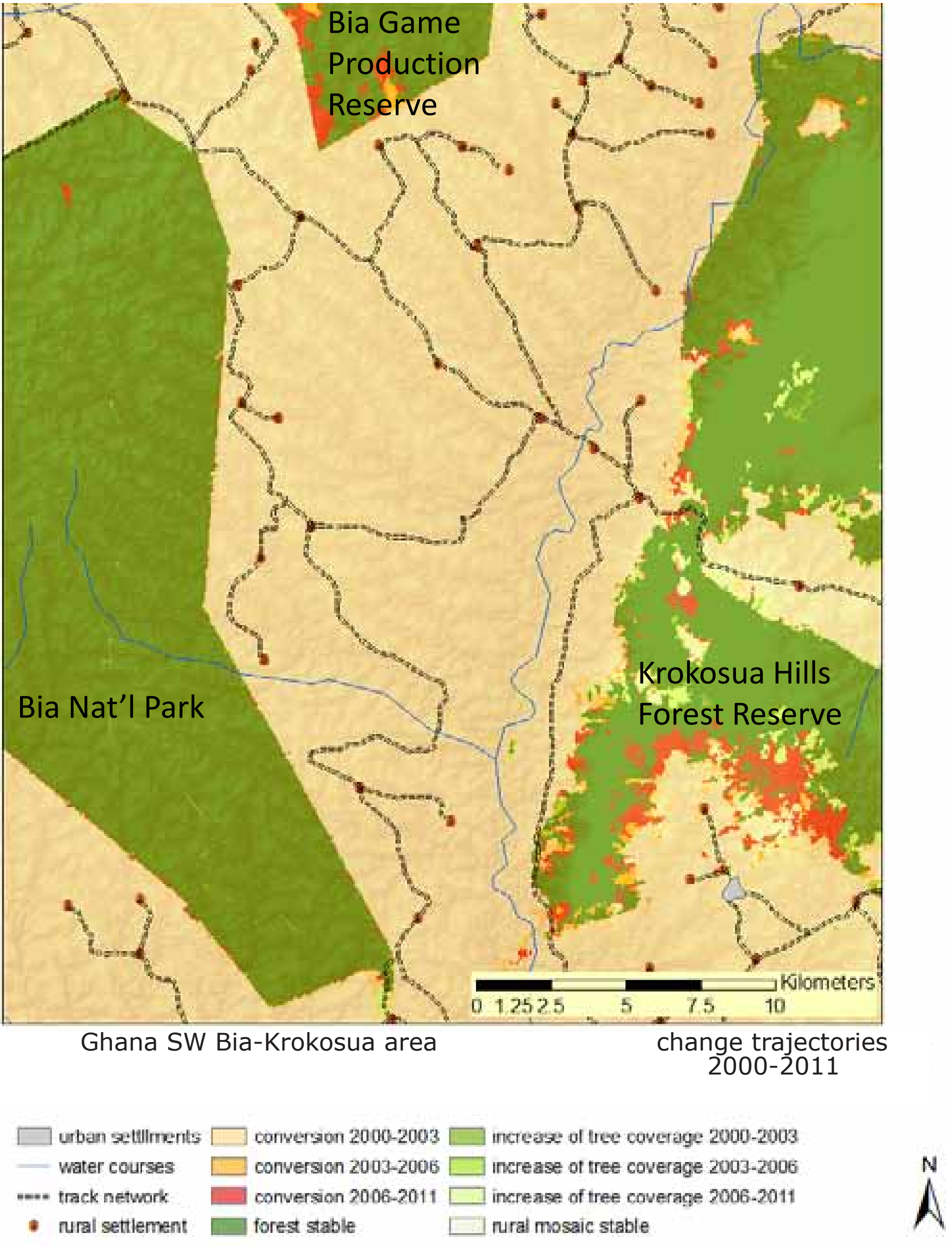

Figure 1. Land-use change trajectories, 2000-2011.

Table 1. A comparison of mean input use in 2000/01 prior to fertilizer interventions and mean input use in 2010/11 during fertilizer interventions and net change in mean cocoa output due to differences in input levels.

Variable	Model simulations		
	2000-2001	2010-2011	Net effect on cocoa output (kg)
Fertilizer (kg)	31	871	1,180
Insecticide (L)	8	11	57
Fertilizer carryover index (0 to 4)	0.0680	1.94	505
Mass spraying (no. of sprays)	0	1.63	106
FFS-trained (producer freq, %)	0	5.88	85
Subtotal			1,934
Yield in 2010 (kg/ha)			535
Predicted yield at 2,000 input intensity (kg/ha)			174

The intensification policies initiated in the early 2000s focused on the acquisition and distribution of subsidized fertilizers and pesticides to farmers. The impact of these policies on yields and incomes was evaluated by comparing predicted outputs at 2000 and 2011 levels of input use with a micro-econometric model of household cocoa production constructed with data from the household survey (Table 1). Yields in the benchmark nearly tripled mainly because of the increased use of fertilizers and household income doubled (Gockowski et al. 2011).

Supporting smallholder fertilizer use instead of forests through REDD

The objective of Reducing Emissions from Deforestation and Forest Degradation (REDD) is to reduce GHG. The method is designed to use market valuation and financial incentives to reward deforestation agents, such as the cocoa farmers of Ghana, for a reduction in emissions.

To produce the output achieved in the benchmark area of our study using the extensive cocoa technology of 10 years ago would require an additional 150,000 ha of rainforest. The amount and value of carbon not entering our atmosphere because of avoided deforestation are an external value that is not captured in the market price received by the farmers intensifying production. Consequently there will be a socially suboptimal level of investment in intensification. REDD is envisaged as a mechanism for addressing this market failure.

Outlook

Fertilizer use in Africa is the lowest of any region in the world. Not only does this perpetuate poverty it also contributes to emissions of GHG and loss of biodiversity. We have developed a methodology

Cocoa plants and pods, Ghana. Photo by IITA.

for determining the amount of deforestation avoided through increased use of fertilizer. Thus, it is a relatively simple matter to value the emissions that are also avoided. More difficult is the question of how to distribute these resources so as to correct this perceived market failure. Directly paying farmers for environmental services has proven to be a costly endeavor and has rarely been successful with smallholders. As an alternative we propose a government-to-government transfer of earmarked funds for supporting agricultural intensification through investments in improved public infrastructure, extension services, agricultural research, and, yes, fertilizer subsidies. There is a risk that more productive technologies lead to greater deforestation, at least at the local level.
To address this, a portion of the REDD funds should be used to enforce protected forest boundaries from encroachment. When properly implemented, agricultural intensification can relieve poverty, conserve biodiversity, and reduce emissions of GHG.

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Well-managed hillside, Rwanda. Photo by IITA.

The IITA NRM Team:

Natural resource management is key to increasing farm productivity

IITA has brought back the focus on natural resources management (NRM). Currently, NRM is one of the Institute's four research themes and represents a very strong disciplinary group that is involved in several CGIAR Research Programs including te IITA-led HUmidtropics. Meet the NRM team.

Bernard Vanlauwe leads the Central Africa hub and the Natural Resource Management research area. In this capacity, he also has oversight for the Consortium Research Programs (CRP) on Humidtropics; the Water, Land, and Ecosystems; and Climate Change and Agricultural Food Security. Before joining IITA, he was the leader of the Integrated Soil Fertility Management (ISFM) program of the Tropical Soil Biology and Fertility research area of CIAT (TSBF). In a previous stint at IITA and the Catholic University of Leuven, Belgium, he focused on unraveling the mechanisms underlying nutrient and soil organic matter dynamics in tropical agroecosystems. He is based in IITA/*icipe*, Nairobi, Kenya.

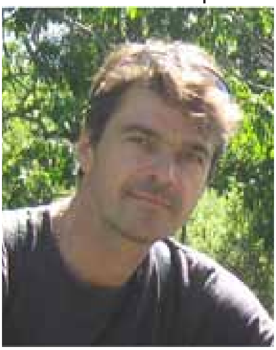
Robert Abaidoo is a Soil Microbiologist. He has experience spanning over 25 years of soil microbiology research on soil fertility improvement, natural resource management, plant nutrient use efficiency, evaluation of biological and chemical products for improved crop and soil productivity and graduate student training in close collaboration with national institutions in sub-Saharan Africa. He coordinates and manages R4D-oriented projects in Ghana.

Richard Asare joined IITA as the Regional Cocoa Agroforester in 2006. For the past 11 years he has been involved in research studies across East, West, and Central Africa looking into agroforestry tree seed distribution pathways and researching on forest trees that are preferred by farmers and recommended by researchers compatible with cocoa. His current research area focuses on

the resilience of cocoa agroforests to impacts of climate change: looking at the relationships between on-farm shade diversity, climate variables, and cocoa production. This is a collaborative PhD research with Copenhagen University.

Steve K. Boahen is a Legume System Agronomist based in IITA-Mozambique. His main research interests include the development of improved crop management technologies for legume-based cropping systems with a focus on identifying physiological and management constraints to soybean and cowpea productivity, developing efficient nutrient management, inoculation methods for enhanced nodulation and N2 fixation and community-based seed system. He is involved in participatory research and works with University staff, students, farmers and farmers' associations and NARES partners.

Danny Coyne has worked in tropical agriculture since 1989, beginning as a village extension officer in rural Tanzania. He has spent most of his working life traversing Africa, working at both the national program and international research institute levels. With specialization in nematology, he is one of the few nematologists in Africa. Of late he has broadened into the wider field of soil health in relation to plant host-pest-antagonist relations and the ecological aspects. Training underscores all of his work, whether at the farmer, technician, or academic level.



Mahamadi Dianda is a Soil Microbiologist working on the promotion of biofertilizers in Sahelian agrosystems. Since June 2012, he has been leading the Nigerian component of the N2Africa project. He is also the the inoculant specialist; he promotes the establishment of legume inoculants facilities in West Africa, and strengthens the adoption of inoculant technologies by smallholder farmers across the sub-Saharan Africa. Formerly, he was working at the national research institute of Burkina Faso contributing to symbiosis and nutrition of tree crops. He holds an M.Sc. (Senegal) and Ph.D. (Canada).

Jim Gockowski is an Agricultural Economist whose interests include agricultural and resource economics focusing on African agriculture. His special interests include primary commodity production and marketing, food security, agricultural research policy, productivity growth, and applied econometrics. He had been actively engaged in the Sustainable Tree Crops Program (STCP) in Ghana for many years. He has a Ph.D. on Agricultural Economics from the University of Florida, USA.

Stefan Hauser is a Systems Agronomist with 25 years of research experience in West and Central Africa. His background is in soil science and soil biology in the humid forest zones of Nigeria and Cameroon. Now based in IITA-Nigeria, he recently returned from DR Congo after formally establishing IITA-DR Congo and conducting an academic training program for the Congolese national agricultural research system. He currently works on cassava and yam agronomy and plant nutrition in Nigeria, Ghana, Cameroon, and DR Congo.

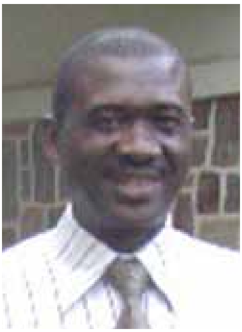
Martin Jemo is a Cameroonian working as a Soil Microbiologist at IITA. He obtained his Ph.D. in Plant Nutrition in 2005 from the University of Hanover, Germany. His research interest is centered on the plant/soil interface to understand the contribution of soil beneficial microorganisms in enhancing plant nutrient uptake and growth under the small-farmer field context of the tropics. The mechanisms that these important soil groups of (micro)-organisms exert to facilitate nutrient acquisition, restore the natural soil fertility, and maintain soil health in the context of diverse small-farmers' heterogeneous fields are also of concern.

Alpha Yaya Kamara is a Systems Agronomist. He has extensive experience spanning over 20 years in the fields of agronomy, soil fertility management, crop science, natural resource management, stress physiology, and farmer participatory evaluation of technologies; also monitoring and evaluating projects jointly implemented with national institutions in sub-Saharan Africa. He coordinates and manages several R4D-oriented projects that are meant to improve rural livelihoods in West and Central Africa. He currently heads the IITA research station in Kano, and leads the CRP on Water, Land, and Ecosystems at IITA.

Cargele Masso is IITA's COMPRO-II Project Leader since July 2012. Before that, he had worked as a regulatory officer in Canada. He holds a Ph.D. in Soil and Environmental Science, an M.Sc. in Environmental Science, and an M.Sc. and B.Sc. in soil chemistry and plant nutrition. He also holds a Certificate in Project Management. His scientific publications are in the area of soil analysis and improvement, and fertilizer quality.

Christopher Ngosong is from Tiko, South West Region of Cameroon. He obtained a B.Sc. degree at the University of Buea Cameroon in 2001, M.Sc. at the University of Hohenheim Germany in 2005, and Ph.D. at the Humboldt University of Berlin, Germany in 2011. He had worked as a research assistant at the University of Hohenheim, Technical University of Darmstadt, and Humboldt University of Berlin between 2005 and 2011; was a Postdoctoral Fellow at the University of McGill, Canada, between 2011 and 2012, and postdoctoral fellow at IITA since August 2012. He specialized in Soil Science/Agricultural Production and Natural Resource Management.

Emmanuel Njukwe is Associate Scientist, IITA-CIALCA, based in Burundi. He coordinates partnerships in the African Great Lakes region with local research, farmers, and development partners with a special focus on outscaling technologies and training tools to end-users. He has been working at IITA since 2001. He initiated the concept of mother gardens for further propagation of healthy banana suckers which can be readily distributed and handled by farmers. Emmanuel has an M.Sc. Agronomy (Soil Science) from the University of Ibadan, Nigeria, in 2000 and is presently a Ph.D. Fellow under the JSPS Ronpaku Fellowship Program, Kyoto University, Japan.



Anne D. Turner is currently the Extension/Dissemination Specialist for the N2Africa Project, which promotes production and utilization of grain legumes towards multiple goals, especially improvement of soil fertility. She has been working in agricultural development in many different parts of Africa for 21 years. She holds an M.Sc. (1986) and Ph.D. (1993) from Cornell University in the USA.

Piet van Asten is a Systems Agronomist at IITA-Uganda working on improving the productivity and resilience of perennial-based farming systems (coffee, banana, cocoa) in Africa's humid zones. During his 15 years in Africa, he also worked on peri-urban vegetable gardening in South Africa (UWC) and irrigated rice schemes in West Africa (AfricaRice). He holds a Ph.D. degree in soil science and agronomy from Wageningen University with a strong emphasis on soil quality and farming systems research. He has proven experience with linking research to development through participatory research and backstopping of out-scaling partners.

Carlos Pérez del Castillo:
Business unusual for CGIAR

Carlos Pérez del Castillo is from Uruguay. He is the Chair of the Consortium Board, which governs the CGIAR, the global partnership of research and development centers that work together for poverty alleviation, of which IITA is only one of 15 centers.

He is also an independent international consultant involved in various assignments with governments, private sector, and international organizations.

In July, he visited IITA accompanied by CGIAR Consortium Chief Executive Officer, Frank Rijsberman; the new IITA Board Chair, Dr Bruce Coulman; and the Directors General of Africa Rice, Dr Papa Seck, and the International Livestock Research Institute, Dr Jimmy Smith.

In this interview, he talks about the new partnerships that is the CGIAR, its one-strategy approach, and IITA's role in the scheme of things.

How far has this visit to IITA met your expectations?
I am leaving with a feeling of enrichment, with a much better knowledge of the work you are doing here. I am also leaving with a sense of reassurance with regard to the support that IITA is willing to give to the reform. It has very much to do with identifying priorities that need to be met in the short run. I think it was a very useful visit.

We were able to talk to the scientists to see the good quality science they are doing in various fields, the degree of engagement, commitment, and passion they have for their work. We were quite happy with the visit.

How prepared is the new CGIAR to tackle food insecurity as we approach 2050?
Let me put it the other way round: if we were stuck with the former way of doing research with 15 centers acting independently with different mandates, we would have never been able to tackle the challenges

effectively. At the moment, we have several new challenges, which required a new approach and which also required institutional and governance changes and those are exactly what we are doing.

The new approach is one strategy for all the centers, collective action among them so that people who are working on crop improvement will do research that is integrated with those who are working on natural resource management, public policies, and institutions. And we are also giving a higher degree than in the past to partnerships because we are convinced that research will produce international public goods but unless they are picked up by the national research institutions, universities, and farmer organizations, etc., we will not have impact on the ground.

Therefore, I think that research will certainly be part of the solution to the challenges on poverty, world food insecurity, resource management... probably not the whole solution but I am sure that agricultural research is very much needed to meet these challenges whether it is climate change, food price volatility, energy—food crops being diverted to biofuels—and feeding the growing population. We are going to have 9 billion people by 2050 and we have less water and degraded lands, fish stock depletion, so we need to find ways and means of doing business differently, and we are doing that in the CRPs.

What role do you see for IITA in achieving these goals?

IITA has embarked on and will be leading one program on production systems that should be given much greater attention than in the past. In the past, most of the research was centered around commodities or natural resource managemen, but I think that this production systems approach—bringing together all the resources from different centers—is likely to make an impact on the livelihood of the poor in different ecosystems and obviously, this is a new thing.

I think that IITA, by having this program approved and leading it, will certainly bring the number of solutions that couldn't be achieved on an individual mandate. So, IITA has a very important role to play. IITA is also playing a role in other CRPs, not only on production systems. I believe that this is the most important one.

Infrastructure is important to research. Is there any plan to upgrade the current infrastructure that will tackle tomorrow's challenges?

The question of infrastructure is very much in our agenda. Part of these demands can be met through the overheads in the CRPs; part will require additional attention. This is why at the moment we have a working group looking at the needs, the situation, and the cost of the infrastructure in the different centers.

Researcher in Bioscience lab. Photo by IITA.

Once we have these and we know exactly what the needs and the costs are, then we also need to think of the cost of these needs in the future.

In the past, we were replicating the same type of things in different centers. There may be economies of scale in doing these in one ore two centers rather than having them in all… so we are looking into this; we are presenting a proposal to donors. We have to do it in an intelligent manner and think of the needs of the future to be successful.

What message do you have for IITA staff?

The message to staff is one of reassurance that we in the Consortium are working for their interest. I think in the last few years, there has been a lot of misconception as to our role, our contribution, and our complementarities. Having spoken to the scientists and staff at IITA and seeing the way they work, I can reassure you that what we are striving for—on the one hand, obtaining more finance for the work they do, and on the other hand, cutting down on reporting requirements, which absorb a high percentage of their time instead of emphasizing and putting all their efforts in quality research—would be met.

I think the reform will be much in the interest of all the centers. I don't think that finance at the end of the day will be a major constraint if we produce value for money. And this is exactly what I would recommend them to work for—very clear outcomes that can be measured, and I reassure them that we will be supporting them in this task.

Maize breeder Abebe Menkir inspecting maize plants in the field. Photo by IITA.

FRONTIERS

Effective commercial products for farmers

Martin Jemo, m.jemo@cgiar.org, Cargele Masso, Moses Thuita, and Bernard Vanlauwe

Background and issues

More and more commercial products, such as biofertilizers, biopesticides, and chemical agro-inputs, are being sold to smallholder farmers in sub-Saharan Africa (SSA). However, their quality and efficacy, especially for the microbiological products, are not properly evaluated before they are commercialized, because regulations are lacking or inadequate. There is a crucial need to implement appropriate regulatory mechanisms.

When microbiological products are used as directed, they are generally more environmentally friendly than synthetic fertilizers. Also, they mainly improve soil fertility by either biological nitrogen fixation (BNF) (rhizobium inoculants) or by increasing the availability or uptake of plant nutrients already in the soil (e.g., phosphorus-solubilizing *Pseudomonas putida*). Unlike microbiological products, synthetic fertilizers N and P chemical fertilizers) are sometimes associated with nutrient loss to the environment causing greenhouse gas emissions or eutrophication. Hence, one of benefits of using microbiological products in integrated soil fertility management (ISFM) is to preserve the natural resource from degradation, while sustaining adequate crop production.

Farmer screening soybean varieties in Kabamba, DR Congo. Photo by IITA.

Martin Jemo, Soil Microbiologist, IITA, Ibadan; Cargele Masso, Project Manager, COMPRO-II, IITA/icipe, Nairobi; Moses Thuita, Ph.D. student, CIAT-Kenya; and Bernard Vanlauwe, R4D Director for the Central Africa Hub and NRM research area, IITA.

The goal of the Commercial Products (COMPRO-II) project is therefore to improve crop yields, improve food security, and minimize the negative impacts of bad or inadequate agricultural practices on the environment.

The project is built on public-private partnerships to develop effective laws and regulations for biofertilizers and other agro-inputs in SSA. It is expected that the large-scale impact of this project will be a significant reduction of inefficacious agro-inputs in the marketplace, resulting in improved crop yields.

Product screening

Products evaluated under the COMPRO project are grouped into three categories: I: rhizobium inoculants, II: other microbial inoculants, and III: non-microbiological products. However, COMPRO-II mainly focuses on categories I and II.

The product evaluation has three key steps: laboratory/greenhouse testing, field testing, and the application of appropriate ISFM (Fig. 1). An additional step consists of the scaling up of the most promising products retained after the three key steps.

Overview of COMPRO-I results

Over 100 commercial products from the three categories were evaluated under field conditions in Kenya, Nigeria, and Ethiopia from 2009 to 2011 in the first phase of the project (COMPRO-I). A significant economic benefit to farmers was found for only a few products (Table 1). On average, the benefit–cost ratio (BCR) for rhizobium inoculants in soybean was found to be US$4.1/ dollar and maize seeds coated with plant nutrients resulted in a BCR of $4.6/ dollar. A BCR of 2.5 is considered satisfactory for the adoption of the technology. The photo below also shows a significant growth improvement for faba

Faba beans treated with a rhizobium inoculant: (left) Faba beans untreated with the rhizobium inoculant, (right) in a demonstration trial in Ethiopia.

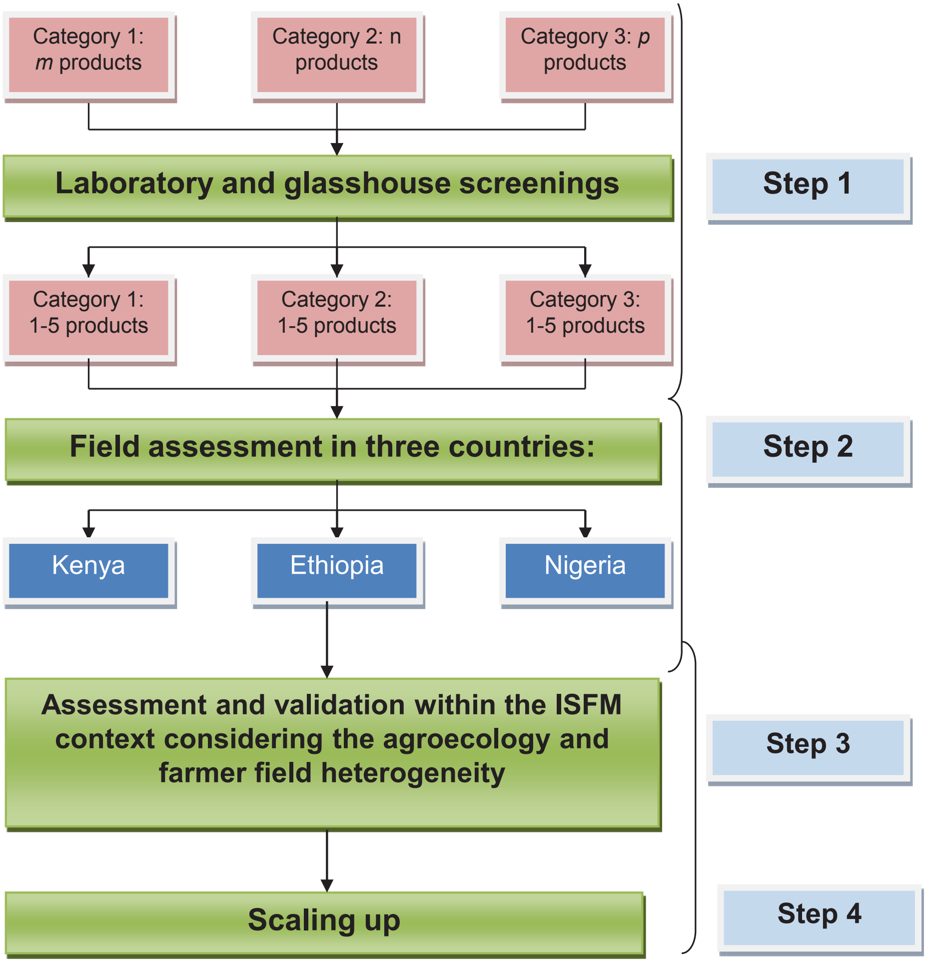


Figure 1. Screening framework of commercial products in Ethiopia, Kenya, and Nigeria under COMPRO-I.

bean following treatment with a rhizobium inoculant.

Analytical tools

A better understanding of the fate and dynamics of the strains in microbiological products after their application to the soil requires adequate analytical tools. In COMPRO-I molecular tools to detect the Mitochondrial Large Subunit (mtLSU) DNA of the isolate *Glomus intraradices* in commercial products (e.g., Rhizatech) was developed (Fig. 2). The yield increase following the application of Rhizatech was associated with faster root colonization by arbuscular mycorrhizal fungi (AMF) as determined by the mtLSU DNA tool.

COMPRO-II is further investigating the information provided by a

Table 1. Yield increase and benefit-cost ratio of selected products evaluated under various field conditions in Ethiopia, Kenya, and Nigeria.

Product	Crop	Yield increase over the control (%)			Benefit-cost ratio (BCR)		
		Ethiopia	Kenya	Nigeria	Ethiopia	Kenya	Nigeria
Legumefix	Soybean	74	75	2.70	NA	11.0	NA
RACA6	Soybean	ND	50	2.04	NA	ND	NA
Conventional	TC banana	ND	ND	ND	NA	ND	NA
Rhizatech	TC banana	ND	ND	2.70	NA	ND	NA
Agroleaf high P	Faba bean	38.7	ND	ND	NA		NA
Agroleaf high P	Maize	ND	43	2.17	NA	0.9	NA
Teprosyn	Maize	ND	45	2.58	NA	4.6	NA
Turbo Top	Faba bean	19.4	ND	ND	NA	ND	NA
Turbo Top	Maize	ND	51	ND	NA	ND	NA

ND = Not determined, NA = Not available

certain region of AMF DNA (mtLSU) and the use of Real Time PCR approach to discriminate different species and isolates of AMF. For example, such tools will be used to determine factors that control BNF in cowpea, a crucial food crop, to develop appropriate inoculants for the benefit of smallholder farmers in Africa.

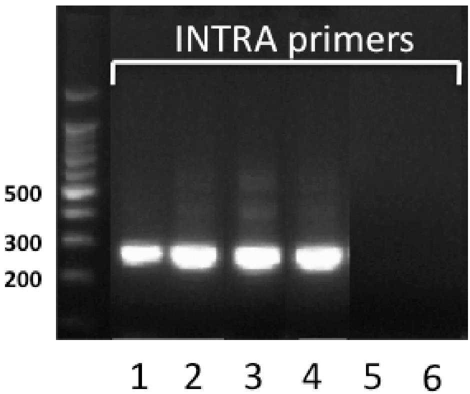


Figure 2. Electrophoresis gel showing fragments amplified with the "INTRA" primers targeting the ribosomal DNA of Glomus intraradices.

Future plans

Based on the economic analysis, a relatively low percentage of the commercial products evaluated under COMPRO-I showed a significant benefit to smallholder farmers. Hence, there is a need to implement adequate regulations to prevent the proliferation of inefficacious products in the marketplace and also to disseminate the most promising products by increasing farmers' awareness about them. Such a goal can be reached only when adequate resources are available. COMPRO-II intends to address those issues based on the lessons learned from COMPRO-I. Scaling-up of efficacious microbiological products will not only contribute to improved crop yields, increased food security, and reduced rural poverty, but will also, when used in adequate ISFM, contribute to preventing agricultural land degradation caused by a lack of agricultural inputs or the heavy application of chemical fertilizers.

Inadequate crop production systems generally result in degraded agroecosystems and reduced crop yields, and therefore have negative impacts on NRM. Biofertilizers are considered environmentally friendly and, when properly used, contribute to improved soil fertility (e.g., BNF and phosphorus availability), and preserve natural resources. However, in SSA, many smallholder farmers are not familiar with those products, while regulations are virtually non-existent in many countries. The COMPRO project intends to address those gaps by: (1) screening commercial products including biofertilizers through a stringent scientific scrutiny, (2) communicating information on, and disseminating products proven best or promising, and promoting ISFM, (3) developing adequate regulations to ensure the safety, efficacy, and quality of commercial products, and (4) building the capacity of countries in SSA to implement and enforce such regulations.

A woman farmer shows inputs used to get the healthy maize crop in the background. *Photo by FIPS.*

COMPRO-II is looking at factors that control biological nitrogen fixation in cowpea, a crucial food crop, to develop appropriate inoculants. Photo by IITA.

CGIAR Research Programs and natural resource management

Bernard Vanlauwe, b.vanlauwe@cgiar.org, Alpha Kamara, Stefan Hauser, and Piet Van Asten

Women farmers are one of the target beneficiaries of the integrated research and development programs that aim to help boost agricultural productivity in the humid tropics. Photo by IITA.

Over the past few years, the CGIAR system has been engaged in a substantial, research-led restructuring of its research agenda through the creation of the CGIAR Research Programs (CRP), supported by a Consortium Office, a Fund for international agricultural research, an Independent Science and Partnership Council, and an Independent Evaluation Arrangement. A total of seven CRPs are now active with several having a crop-specific focus, others a farming system focus, and others addressing themes related to natural resource

Bernard Vanlauwe, R4D Director for the Central Africa Hub, leads the natural resources management research theme in IITA; Alpha Kamara is IITA's CRP leader for Water, Land, and Ecosystems (WLE); Stefan Hauser is the CRP leader for Humidtropics, and Piet Van Asten is the CRP leader for Climate Change and Agricultural Food Security (CCAFS).

management (NRM) or the creation of an enabling environment for the uptake of improved options. IITA is leading the Humidtropics CRP and contributing significantly to the CRPs on Water, Land, and Ecosystems (WLE) and the Climate Change, Agriculture, and Food Security (CCAFS), all of these having significant NRM components. This article highlights these components in the context of the overall CGIAR research framework and the specific contributions of IITA towards the success of these CRPs.

Humidtropics

The humid tropics is home to 2.9 billion of the world's poorest people. It is the part of the world with the biggest gap between its ecological and economic potential and human welfare. The Humidtropics CRP aims to realize more of that potential to improve the livelihoods of the majority of the population and protect their environment and natural resources from the usual rapid degradation when used for agriculture or forest (timber) exploitation. Humidtropics seeks intensification pathways and critical points of intervention to design superior crop, livestock, fallow, and perennial (tree) production systems along with improved soil, water, and vegetation management practices, and the identification of investment strategies for sustainable natural resource base management.

Interventions will increase overall farm and system productivity and income while improving the natural resource base, particularly soil quality. Humidtropics will strategically select critical entry points that foster more diverse system components to generate more equitable agricultural growth in which rural communities move beyond commodities, reduce their risks, sustainably manage their natural resources, and effectively reduce rural poverty.

Humidtropics is led by IITA in partnership with the International Center for Tropical Agriculture (CIAT), International Livestock Research Institute (ILRI), World Agroforestry Centre (ICRAF), International Potato Center (CIP), Bioversity International, International Water Management Institute (IWMI), International Centre of Insect Physiology and Ecology (*icipe*), Forum for Agricultural Research in Africa (FARA), The World Vegetable Center (AVRDC), and Wageningen University. It will operate in various action areas in Africa, Latin America, and Asia with the Western Humid Lowland and the East and Central African Highland Action Areas led by IITA. Humidtropics is a systems research program that covers all lowland humid and subhumid ecologies (between dry land and aquatic), draws on research in commodity CRPs, and integrates technologies and forecasting ability from the CRPs on Policies and Markets, Nutrition and Health, Water and Land, and Climate Change (see diagram).

Water, Land, and Ecosystems (WLE)

The global population in 2050 will be about 9 billion, with most of the increase between now and then taking place in developing countries. To feed the world in 2050 and beyond, we need to intensify agricultural production. Many observers believe that intensification will cause unacceptable harm to the

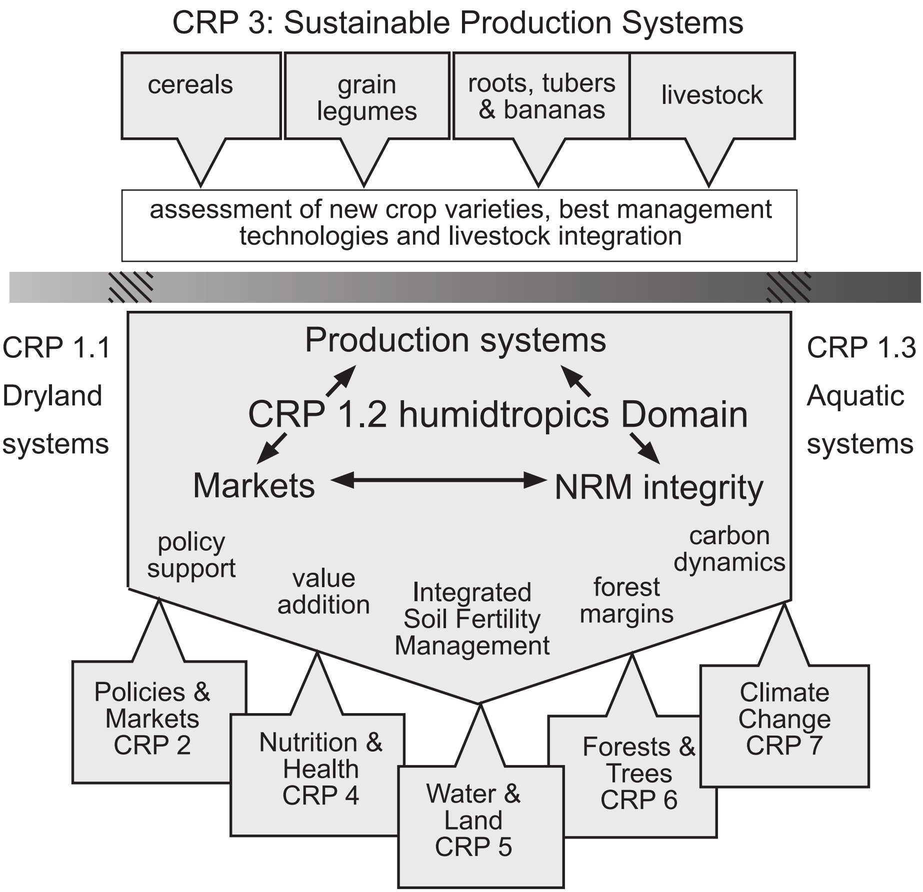


Figure 1. Relationships between Humidtropics and other CRPs

environment, perhaps undercutting the ecosystems that support agriculture. WLE challenges this perspective and examines how we can intensify agriculture while protecting the environment and lifting millions of farm families out of poverty.

To achieve the vision of sustainable intensification, we must redouble our efforts to increase agricultural productivity, while protecting the environment, and we must conduct new and integrative research on agricultural and ecosystem interactions. Consequently the objective of WLE is to learn how to intensify farming activities, expand agricultural areas and restore degraded lands, while using natural resources wisely and minimizing harmful impacts on supporting ecosystems.

Within the broad topic of WLE, we have identified five strategic research portfolios (SRPs): Irrigated Systems, Rainfed Systems, Resource Reuse and Recovery, River Basins, and Information Systems. The Rainfed Systems SRP, to which IITA is contributing, targets 80% of the world's farmland that is largely rainfed. Although many farmers in rainfed areas capture and store water for use as supplemental irrigation, millions more entirely depend on rainfall. In many areas, increasing populations have placed substantial pressure on rainfed cropland and on the land and water resources used by livestock. As a result, the land and water resources in many areas are degraded and unproductive. WLE researchers will determine ways to restore degraded resources using multifunctional landscape management approaches, and will develop integrated soil and water management techniques.

In pastoral systems, extensive land degradation and the loss of access to water and land resources threaten the livelihoods of millions of pastoralists, leading to conflicts in some areas. WLE researchers will determine the changes in land and water management and the complementary policies needed to support pastoral livelihoods. The Rainfed System SRP currently works around five problem sets: (1) Recapitalizing African soils and reducing land degradation; (2) Revitalizing productivity on responsive soils; (3) Increasing agricultural production while enhancing biodiversity; (4) Enhancing availability and access to water and land for pastoralists; and (5) Reducing risk by providing farmers with supplemental irrigation.

Climate Change, Agriculture, and Food Security (CCAFS)

Climate change is an immediate and unprecedented threat to the livelihoods and food security of hundreds of millions of people who depend on small-scale agriculture. To overcome these threats, the CGIAR and Earth System Science Partnership have united through CCAFS, a strategic ten-year partnership. Farmers, policymakers, donors, and other stakeholders are strongly involved to integrate end-user knowledge and needs. Synergies and tradeoffs between climate change, agriculture, and food security are studied to promote more adaptable and resilient agriculture and food systems. CCAFS is structured around four thematic research areas: (Theme 1) Adaptation to Progressive Climate Change, (Theme 2) Adaptation through Managing Climate Risk, (Theme 3) Pro-poor Climate Change Mitigation, and (Theme 4) Integration for Decision Making. Place-based research is focused on five regions: East Africa, West Africa, South Asia, Latin America, and Southeast Asia.

IITA is one of the 15 CGIAR centers involved and it particularly contributes to research on:

- Theme 1 on crop G × E interactions. The major focus is on the IITA crops cassava, maize, soybean, yam, cowpea, and banana, but with other crops in the system being investigated as well, including horticultural crops and tree crops such as coffee and cocoa.
- Theme 2 on plant health × climate change: IITA has a strong plant health team that is currently exploring the

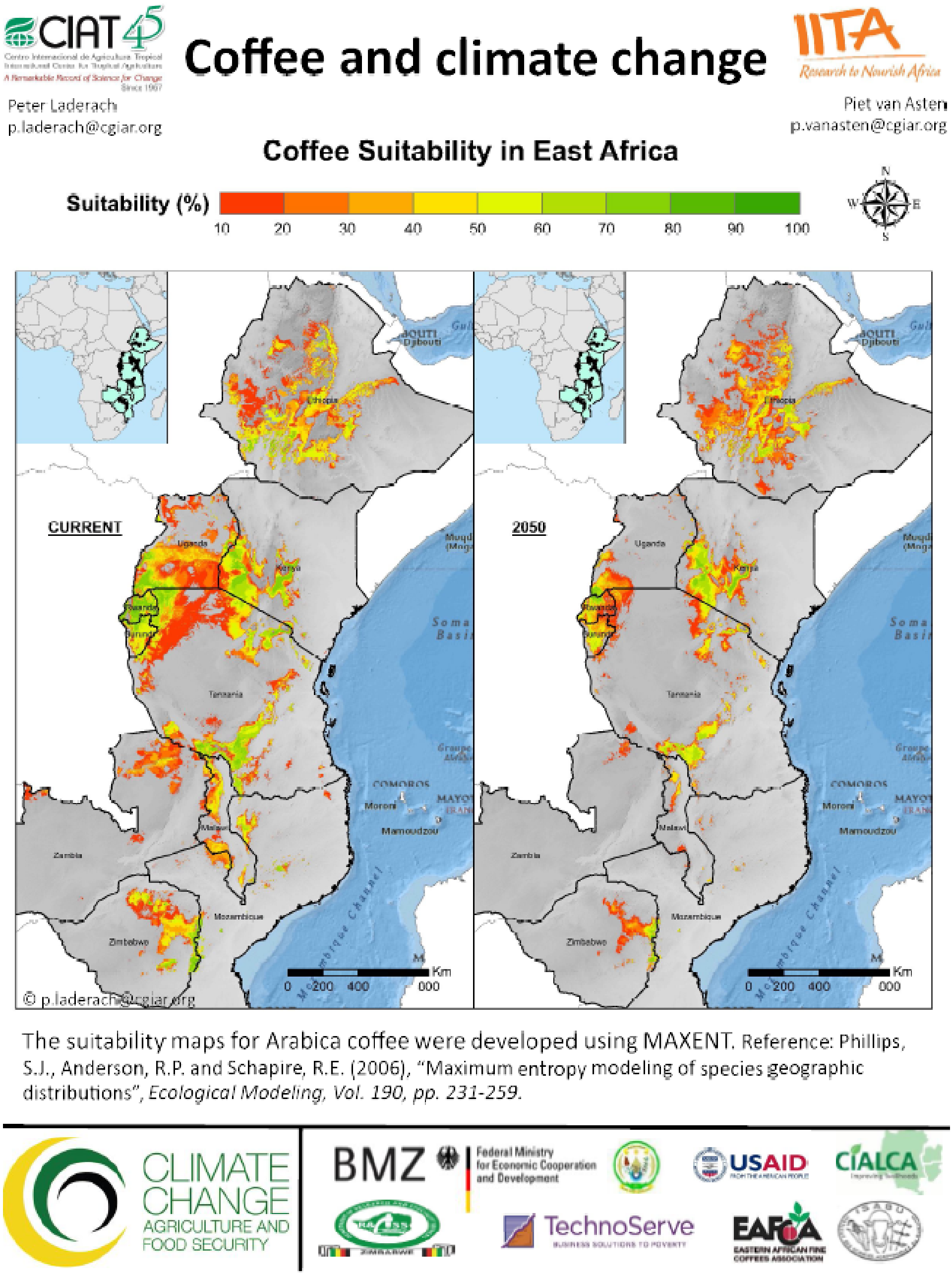


Figure 2. Suitability maps for Arabica coffee were developed jointly with the DAPA team at CIAT with data from national partners across the East African region. The maps were presented to the African coffee community during an IITA-organized African coffee science workshop as a side event of the EAFCA conference in Ethiopia in February 2012.

relationship between climate variables and major pest and disease threats, with the same crop focus as listed under G × E.

- Theme 3 on analyzing trade-offs and synergies in climate change adaptation and mitigation in perennial-based crop systems in the humid tropics: The research focuses particularly on coffee and cocoa-based systems (see page 44 in this issue).
- Theme 4 on communicating the results of the trade-off and carbon-footprinting analysis to the stakeholders, in particular policymakers, certification bodies, and the private sector.

The future of NRM

Most CRPs have moved into an implementation phase and all facilitating structures have been put in place, which is probably the most exciting change in the way of doing business within the CGIAR since its inception. From the foregoing summary, the crucial role of IITA as a whole and the NRM research areas more specifically is clear, especially for the African continent. Although IITA may have lost some of its NRM capacity over the past decade, as shown in some of the articles in this publication, much NRM innovation, strategic thinking, and practical solution development is still happening at IITA and will only be strengthened over the coming decade with the renewed investment of IITA in NRM.

Installation of an erosion control trial, Sud-Kivu, DR Congo. Photo by IITA.

Demand-driven, action-oriented, integrated capacity development for R4D

The overall goal of IITA's training and learning activities is to strengthen the capability of partners in the national agricultural research and extension systems (NARES) to conduct research and training in their own countries. Further, IITA training activities facilitate research collaboration between IITA and the NARES. Thousands of professionals in sub-Saharan Africa have profited from IITA's training and many more benefit indirectly through knowledge they in turn have passed on to others.

Approaches to capacity development

IITA uses a mix of training approaches, which include individual short-term and long-term courses and also group training. The IITA Capacity Development Program consists of:

Professional Capacity Advancement Program (PCAP): The Professional Capacity Advancement Program (PCAP) targets professionals from partner national research institutions and universities. Young and bright researchers (BSc or MSc degree holders with several years of experience) and fresh PhD degree holders will conduct research in areas of IITA's research in collaboration with Institute scientists.

Graduate Research Fellowship Program (GRFP): The main objective is to enable budding professionals to develop the necessary research skills, attitude, and confidence for a successful career in agriculture. The program focuses on providing quality research experience in the areas of IITA research. The research projects must contribute to IITA's research objectives. It is assumed that students will use their results to fulfill their degree requirements at their universities. The experienced IITA scientists will act as co-supervsiors. The long-term goal is for the IITA-trained students to take up positions in research institutions in their home countries.

Short-Term Courses - Non-degree / Group training: This is organized in the form of individual training for scientists, extension workers, NGO workers, etc., usually referred to as Research Training Associates (RTAs) or as a group activity for various interest groups or farmers. IITA scientists are involved in numerous external training workshops with projects. These are driven by the needs of the research-for-development projects and can involve both IITA scientists and external experts as trainers. To remain relevant, IITA scientists must continually impart new knowledge and skills to national programs. Significant numbers of scientists, extension workers, NGO workers, and farmers have been trained under this program.
Short-term Individual and Group Training courses provide one of the most cost-effective means of rapidly disseminating new technologies.
In collaboration with scientists, appropriate courses will be developed, packaged, advertised, and marketed aggressively to NARES, NGOs, universities, community-based organizations, and donors.

Interns/Volunteers: Interns and volunteers are students from NARES or developed countries currently enrolled in their first degree, or fresh graduates, who want experience to help them with their career decisions or to complete requirements for their degrees. They work within a relevant program at IITA for periods ranging from one month to 6 months.

For more information contact:
Zoumana Bamba, Head, IITA Capacity Development, z.bamba@cgiar.org

In its 45 years of existence as Africa's leading research partner, IITA has trained more than 74,000 people in Africa and elsewhere. Some of these beneficiaries today occupy strategic positions in Africa.

The IITA **R4D Review** is a six-monthly magazine intended to help IITA and research and development partners, investors, collaborators, and beneficiaries discuss and develop the best new ideas for people creating, leading, and transforming tropical agriculture.

The R4D Review has six sections:

Features provides an in-depth, rigorous presentation of a significant advance in research-for-development thinking and its application to real world needs that help establish an intellectual agenda for discussion—and change—within the organizations and for society at large.

Best Practice describes the how and why behind a successful research for development achievement.

Tool Box provides a nuts-and-bolts explanation of a useful research-for-development tool that can be translated into action in many different situations.

Who's Who recounts a personal story of an IITA staff that contains lessons for colleagues.

Looking In features people from outside IITA whose ideas hold salient lessons for those within IITA.

Frontiers is a forum for forward-looking articles that explore new science and technology trends affecting development needs (i.e., starting projects or technologies in the pipeline).

CONTRIBUTIONS needed

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